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TECHNOLOGY PLANNING AND
MANAGEMENT

by

Douglas Desmond Cowper

A PhD thesis submitted in fulfilment of the
requirements for the degree of

Doctor of Philosophy

University College London

2005

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Abstract

TECHNOLOGY PLANNING AND MANAGEMENT

by Douglas Desmond Cowper

The term 'Technology' is widely used in our society and is also loosely defined. It is often used to gloss over intractable problems by implying 'we have the technology' and therefore reassuring everyone that everything is going to be okay! So, what are technology, and technology planning and management, why do we need technology, and where and how do we plan for technology to avoid it continuing to be a 'grey mist' of missed opportunity? This PhD thesis sets out to explore the "What", "Why", "Who", "Where", "When", and "How" of technology planning and management.

A review of existing tools and techniques established some of the "how" of technology planning and management and identified some gaps. The most significant of these gaps is a lack of a "lifecycle" framework for technology planning and management that will allow an organisation to know when and where to use the appropriate tools and techniques. The existing tools were also modelled using the Unified Modelling Language (UML) to gain a deeper insight into how they worked.

A study was conducted into two instrumentation supply chains and resulted in 101 observations associated with technology planning and management. However, the most important observation was that the majority of organisations were not using a formal process for technology planning and any that were carried out were ad hoc. The most common reason for this was the lack of awareness of any formal tools and techniques and any that were used produced dubious results.

The technology planning and management lifecycle model developed addresses the gaps in the existing range of tools, provides a framework indicating when to use particular tools and addresses the issues identified by the study. The aim of this model is to put some science and management back into technology development rather than it just being a good thing to do.

The technology planning and management lifecycle model was tested in part by a hypothetical example and by a series of field trials. The untested parts will need to be explored further through implementation of this model within organisations and any follow-on projects.

The main outcome from this thesis is an improved generic technology planning and management lifecycle model and a tool kit to help tailor it to an organisation's context.

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GLOSSARY

Throughout this document the following terms and abbreviations shall apply.

Terms

Bottom Line	<i>colloq.</i> the underlying or ultimate truth; the ultimate, esp. financial criterion (Allen, 1990, p130). In the case of this project the bottom line refers to the company's profitability.
Bells & Whistles	Refers to the features and functions found on equipment, especially additional features and functions over and above those required to perform a specific task.
Cash Cow	A cash cow is a product or service that has a high market share in a mature market. Growth in this mature market is low and stability is high, therefore the need to invest in the product or service in terms of marketing, development, technology, etc. is less. The relative high market share means that an organisation should be able to maintain unit costs below those of its competitors and hence for the product or service to be a cash provider. (Johnson & Scholes, 1993, p105)
Customer/ End User	Refers to individuals and organisations that procure/use instrumentation in the course of their business and who do not develop instrumentation as part of their core business but rely on it in order to deliver their products.
Final User	Refers to individuals and organisations that use the products of the particular industry of study (in the case of the pharmaceutical industry it is the person(s) who take(s) or administers the drug) and also require instrumentation in order to use the product safely and/or efficiently. For example, organisations that use radioactive products in controlled doses require instrumentation to ensure that these doses are correct.
Instrument	A tool or implement, esp. for delicate or scientific work (Allen, 1990, p614).
Instrumentation	The design, provision, or use of instruments in industry, science, etc. (Allen, 1990, p615).
Measurement System	Are assemblages of instruments and components interconnected to perform an overall measurement function. The system components must not only perform their individual functions properly but must also work effectively with other components making up the system (Wolf & Smith, 1990, p483).

Qualitative Research	Refers to research that uses ethnographic prose, historical narratives, first person accounts, still photographs, life histories, fictionalised facts and biographical/autobiographical materials. (Denzin & Lincoln, 1998, p11).
Quantitative Research	Refers to research that uses mathematical models, statistical tables and graphs, and is usually presented in impersonal, third person prose (Denzin & Lincoln, 1998, p11).
Supplier	Refers to individuals and organisations who design, develop and manufacture instruments for use in laboratory and/or industrial applications.
Technology	The study or use of the mechanical arts and applied sciences (Allen, 1990, p1253). However, Floyd (1997, p1) provides a more in depth definition: <i>“Technology is the practical application of scientific or engineering knowledge to the conception, development or application of products or offerings, processes or operations”</i> .

Abbreviations

AMLCD	Active Matrix Liquid Crystal Display
CADMID	Concept, Assessment, Development, Manufacture, In-service and Disposal (United Kingdom Ministry of Defence Smart Acquisition lifecycle)
CCD	Charge Coupled Devices
COTS	Commercial-Off-The-Shelf
DEFRA	Department for the Environment, Food and Rural Affairs (UK Government)
DTI	Department of Trade and Industry (UK Government)
EPSRC	Engineering and Physical Sciences Research Council
ESA	European Space Agency
GSK	GlaxoSmithKline
GPS	Global Positioning System
HP	Hewlett Packard
IEE	Institution of Electrical Engineers
IMechE	Institution of Mechanical Engineers
Intersect	Intelligent Sensing Faraday Partnership
ISCAM	Instrumentation Supply Chain Analysis and Modelling project
ISO	International Standards Organisation
MD	Managing Director
MoD	Ministry of Defence (UK Government)
MP	Member of Parliament
MSSL	Mullard Space Science Laboratory
NPL	National Physical Laboratory
OEM	Original Equipment Manufacturer
PERA	Production Engineering Research Association
PERT	Programme Evaluation and Review Technique (Project Management Tool)
PF	Precision Farming
QFD	Quality Function Deployment (diagram)
R & D	Research and Development
SAR	Synthetic Aperture Radar
SBAC	Society of British Aerospace Companies

SWOT	Strengths, Weaknesses, Opportunities and Threats
TRIZ	Teorija Rezhnija Izobretatelskih Zadach (Russian acronym)
UCL	University College London
UK	United Kingdom
UML	Unified Modelling Language
US	United States (of America)

Chapter 1

1. INTRODUCTION

1.1 Background

'Technology' is widely used in our society and is also loosely defined. It is often used to gloss over intractable problems by implying 'we have the technology' and therefore reassuring everyone that everything is going to be okay! For example, Ford & Saren (1996, p1) point out that mentioning 'high technology' or 'technology breakthrough' at company meetings is sufficient to close down informed discussions to a sea of thoughtful nods. Everyone seems to believe that technology is somehow a 'good thing', like being a warm-hearted person, however it is not easy to understand how to develop it or capitalise on it. Technology is like a grey mist that shadows a company's products and processes. The products and processes can be easily described, technology cannot. The products and processes are tangible, technology is not (Ford & Saren, 1996, p1).

As an Engineering Manager in a company developing instrumentation for the aerospace industry, the author was responsible not only for the engineering required to develop new products, but also for determining what technologies the company needed to invest in to deliver these products. The author experienced a number of difficulties in planning and managing technology that was partly due to a lack of awareness of the tools available, partly due to no clear lifecycle process, partly due to an unclear business case for the development, and partly due to not enough time being allocated to the implementation of the strategy. The author is not alone in experiencing these issues. The majority of the organisations studied in this thesis also faced the same issues.

1.2 Generic Technology Planning and Management Issues

So, what are technology, and technology planning and management, why do we need technology, who needs it, and where and how do we plan for technology to avoid it continuing to be a 'grey mist' of missed opportunity? The following sections explore the "What", "Why", "Who", "Where", "When", and "How" of technology planning and

management, and the purpose of this PhD thesis is to address the generic issues of “When”, “Where”, and “How”.

1.2.1 What Is Technology Planning and Management?

Technology is the “ideas”, “knowledge”, “know how”, “devices” or “artifacts” that is owned by individuals and organisations and includes the appreciation of technical domains and associated skills, and the capability to use/deliver technology through contracts, organisational structure, facilities and processes (Smith, 2002, p2).

Technology provides routes to product differentiation, reduced costs, new business opportunities, and supports strategic change (Floyd, 1997, p3). Technology planning allows organisations to manage the way technology affects their business and how their business affects the development of technology. Technology planning aids the implementation of companies’ strategic vision and allows them to manage explicitly the application of technology for the longer term (Floyd, 1997, pp2-23).

Smith (2001) identifies that Technology Planning addresses issues such as:

- Technology Dependencies
 - How does a company’s bottom line depend upon technology?
- Technology Trends
 - When will new technologies become available?
 - How can you influence their development?
- Market and Competitor Awareness
 - How do competitors use technology?
 - What will provide a competitive edge in the future?
- Acquisition
 - How can new technologies be acquired?
 - How can the acquisition of new technologies be funded?
- Feasibility
 - What are the risks?

However, Braun (1998, p55) points out that planning is only half the story and that this plan needs to be successfully implemented. This implementation is more akin to normal

management activities, as it requires actions and needs to negotiate the buffeting of external forces, hence technology needs to be planned and managed.

1.2.2 Why Do We Need Technology Planning and Management?

Changes in technology can erode competitive advantage by reducing product life cycles and hence reduce the chance to recoup investment in a particular product (Johnson & Scholes, 1993, p80). In addition this technological change can make established products obsolete overnight (Hill & Jones, 1995, p80). Organisations need to be aware of how technology is changing in order to mitigate the risk to their product range and turn the threats into opportunities.

Reinertsen (1997, pp128-130), whilst exploring the product development process, identifies that one of the constraining factors of the development process is the timely arrival of technological solutions to problems. Reinertsen (1997, pp128-130) proposes that one can either wait for the technological solution to become available before starting product development, or develop the technology in parallel. By waiting for technology, the risk to speedy product development is reduced at the expense of efficiently overlapping product and technology development and gaining a competitive advantage. By developing the two in parallel the risk of the technology holding up the product's development is increased.

In order to make these types of decisions, for example, how closely technology development needs to be coupled to product development, one needs to understand, plan and manage technology development. Technology is also a means to an end. Enterprises such as businesses use technology to do their business (even if that is selling the technology). Therefore the acquisition and exploitation of technology must be integrated within a wider enterprise context (such as a strategic roadmap).

1.2.3 Who Needs Technology Planning and Management?

Metz (1996, p118) identifies that linking technology planning with strategic business planning is a continuous major issue among technology intensive companies. However, as products become more complex and there is a reliance on high technology support solutions for even the most basic companies and products, technology has an impact on everyone's lives (Stevens et al, 1998, pp2-4).

All organisations whose products and services have a high degree of “technological choice” need to manage and plan for technology changes and to use appropriate technology decision-making tools. For example “should the military buy fewer very advanced bombers or a larger number of simpler ones if the costs are the same” (Hazeltine & Bull, 1999, p2). This type of trade off decision can be better judged by organisations that have a good insight into where technology is going, what the threats and opportunities are and how they can influence this change.

1.2.4 When, Where and How Do We Plan For Technology?

Having established what technology planning and management is, why we need it and who relies on it?, the next set of questions “How” does one go about planning for technology and what tools are available to facilitate this process, “When” and “Where” should one use these tools are the main subjects of this PhD thesis. Each tool will not always be appropriate for the situation being applied (“one size does not fit all”). However, appropriate tool selection is not helped by the fashionable trends in the use of such tools. For example, there is a current trend in the use of technology roadmaps especially in the DTI (government). A quick search on the internet identifies 459 hits associated with the DTI and technology roadmapping. The uses range from the Earth Observation by the British National Space Centre through the Automotive Innovation Growth Team to Bio, Micro and Nano technologies. Technology readiness levels are currently in favour with the MoD and prime defence contractors to “de-risk” the use of technology in military equipment procurement programmes. The author is not sure why these fashions occur. It could be down to the successful marketing of the latest technique or recommendation from respected advisors or it could be the tool users being disillusioned with the results of the previous tool they used. The latter had been experienced by members of the organisations studied in this thesis.

Therefore appropriate tool selection, by understanding the advantages and disadvantages of each tool, and when to apply the appropriately selected tool are key dilemmas facing the technology manager. This thesis aims to address these generic issues by studying the instrumentation supply chains of the pharmaceutical and agrochemical industries.

1.3 EPSRC / Intersect Faraday Partnership Instrument Supply Chain Analysis and Modelling Project

Organisations require major changes in order to rise to the new challenges of the modern global economy. Papageorgiou et al's (2001, pp275-286) work in modelling and optimising the strategic supply chain in the pharmaceutical industry highlights that all stages of the business value chain are affected by globalisation. Gjerdrum et al (2001, pp1650-1660) identify a key issue in the optimisation of the supply chain as the "*determination of policies that optimise the performance*" and that also ensure "*adequate rewards for each participant*".

So what are these policies that help optimise the supply chain performance? One policy area in the value chain that can be addressed is new product development and technology planning. Ireland and Trevisan (2001, pp49-53) provide a vision of the future, in terms of technological development in this changing environment, that the suppliers of instruments are facing:

"Companies developing products for a connected world set the pace for instrument development. In future, instrument designers will have to maintain their expertise in acquisition technologies and architectures [etc.].. In addition, test and measurement companies must continue to work closely with the technology and industry leaders to ensure that the development of new instruments is closely aligned with the product roadmaps of the end users."

Some of the issues facing companies who rely on instrumentation have been discussed at various Department of Trade and Industry (DTI) Intersect Faraday Partnership meetings. Similar issues have also been identified by Cooper & Schendel (cited by Shaklin & Ryans, 1985, pp101-102) of Purdue University, during a case history study of twenty-two companies in seven different industries, they found that:

- New technologies are mainly initially commercialised by companies outside the threatened industry (One of Porter's (1979) five competitive forces – the force of threat of substitution). Start-up firms are especially likely to innovate new technology whenever capital requirements are not huge.
- Frequently the market size for new technology is pessimistically small due to the innovations initially being crude and expensive.
- Innovations can create new markets that are not open to the replaced technology.

To explore the issues associated with technology planning, UCL's Centre for Systems Engineering was awarded an EPSRC-Intersect Faraday Partnership Flagship Grant to investigate the systems technology issues within instrumentation supply chains. The project's aim was to address the situation in which an organisation depends upon instrumentation to deliver its business process but whose core business is not in the development of instrumentation.

The project's aim was to develop a generic process for generating workable technology plans, initially focusing on the pharmaceutical and agrochemical industries with support from some of the other Faraday Partner companies. These industries, like many others, rely heavily on instrumentation to develop new products, control production processes and determine product quality. However, the technology and development of instrumentation is not a core competence of these companies and as they outsource more non-core activities, they become more reliant on innovation that is not under their control. Thus, the project had to build an understanding of these organisations' instrumentation supply chain and then analyse the sensitivity of their use of instrumentation on their bottom line.

The project involved modelling the companies' business processes and instrument supply chain processes, and providing a technology planning process model. These models were validated and refined for use in analysing the instrumentation supply chain sensitivities within the business model. The analysis was also used to develop the technology-planning model.

The output of the project will ultimately underpin a technology planning service that can be offered to other companies through the Intersect Faraday Partnership – hence the strong support of the Intersect co-hosts, Sira and NPL.

1.3.1 Technology Planning and Management Lifecycle Process Model

A subset of the Instrumentation Supply Chain Analysis and Modelling project is the research topic submitted in this PhD thesis. The technology planning and management lifecycle model developed in this thesis aims to address the key generic issues of appropriate tool selection and when to apply the selected tools. The purpose of the lifecycle model is to enable organisations to tailor the process so that it can be easily incorporated into their business processes. The aspiration is that the implementing organisation takes ownership of

the process so that it can continuously plan and manage its technology rather than be reliant on a third party facilitating or owning the process. For example, as mentioned earlier, roadmapping has gained widespread popularity. It relies on a series of facilitated workshops (market, product, technology and charting) (Phaal et al, 2001, p12). However, how do these workshops integrate within an organisation's planning cycle and what do they do with the maps generated (a similar issue was observed in the farming community regarding yield maps in that the farmers did not know what to do with them once generated)? The roadmapping tool is included as part of the technology planning and management lifecycle model, which provides a framework of when to carry out roadmapping and what the generated roadmaps are used for (decision-making and plan implementation). The lifecycle model also defines the scope of the roadmap to avoid the roadmap getting complicated very quickly, a criticism raised during the instrumentation supply chain study.

The Technology Planning and Management Lifecycle Model supports the modelling approach used by Dr Michael Emes to model instrumentation use and procurement as part of the Instrumentation Supply Chain Analysis and Modelling Project. The three-stage approach for modelling a company that uses instrumentation for Research and Development is summarized in Figure 1 (Emes et al, 2005).

The first stage is to put the activities of the business into context by building a stakeholder model and to see how this influences the business model. This model shows how the business meets the needs of the customer. The modeller can now consider how the business goes about meeting its goals.

The second stage is to examine in detail the instruments that the business currently uses and the processes they participate in to deliver the end product. This is specific to the industry or business in question.

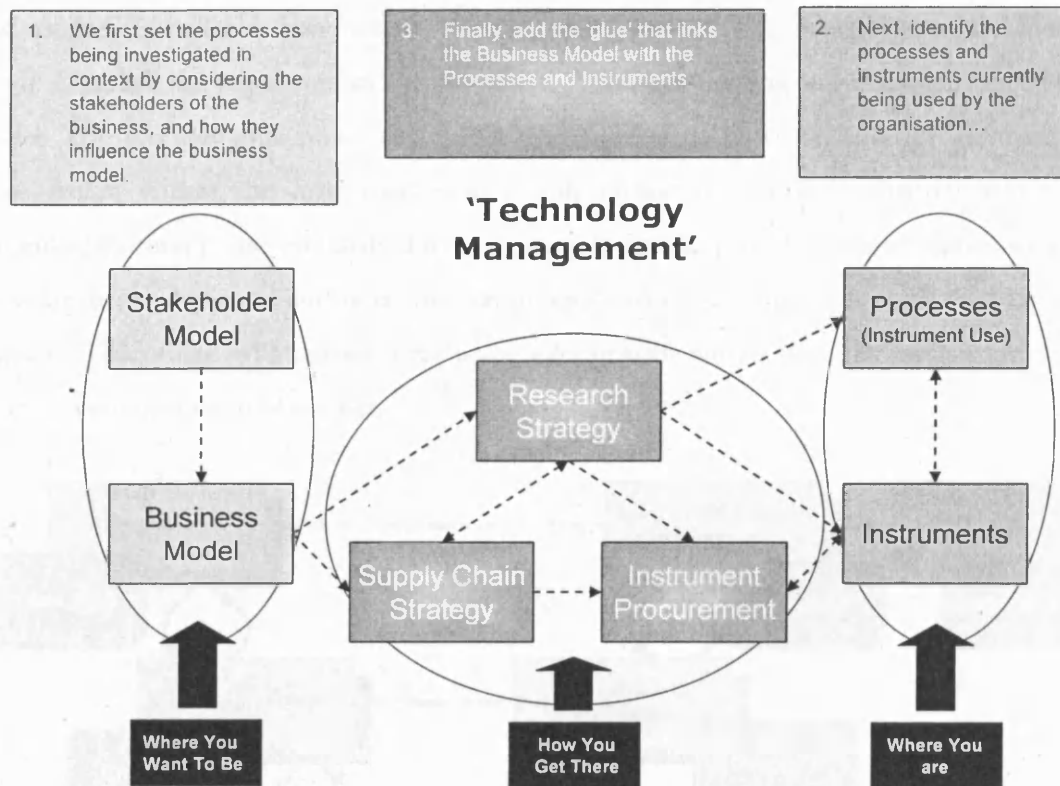


Figure 1 Three-Stage Approach For Modelling A Company That Uses Instrumentation For R&D (Emes et al, 2005)

The third and final stage is to link the 'top down' business model that was described in Stage 1 and ensure that the stakeholders' needs are satisfied, with the 'bottom up' use of instruments and processes by the organisation. This marriage is the function of the Technology Planning and Management Lifecycle Model, which incorporates the company's research strategy (its choice of what areas to research), supply chain strategy (how prospective suppliers are identified and approved, and what the purchasing protocols are) and instrument procurement strategy (roles and responsibilities relating to procurement in the company). It should be noted that Figure 1 refers to the modelling of instrument use for R&D, however, it would be just as valid to replace 'instruments' with 'products', or 'services' etc and the context could be replaced by other business functions or processes. Hence this approach is generic.

To develop the technology planning and management lifecycle process model, to address the issues raised by the Intersect Faraday Partnership and to answer the questions "When", "Where" and "How" do we plan for technology, a Systems Engineering lifecycle

was adopted in order to conduct the research, see Figure 2. The first phase of the lifecycle was to establish the requirements for the new technology planning and management lifecycle model. The requirements phase established the current status of technology planning and management within the instrumentation supply chains of various industrial sectors. In particular, the first phase established what existing tools and processes are available, which of these are being deployed and what the advantages and disadvantages of each are. This first phase also identified what issues were being experienced within the instrumentation supply chain of various industrial sectors.

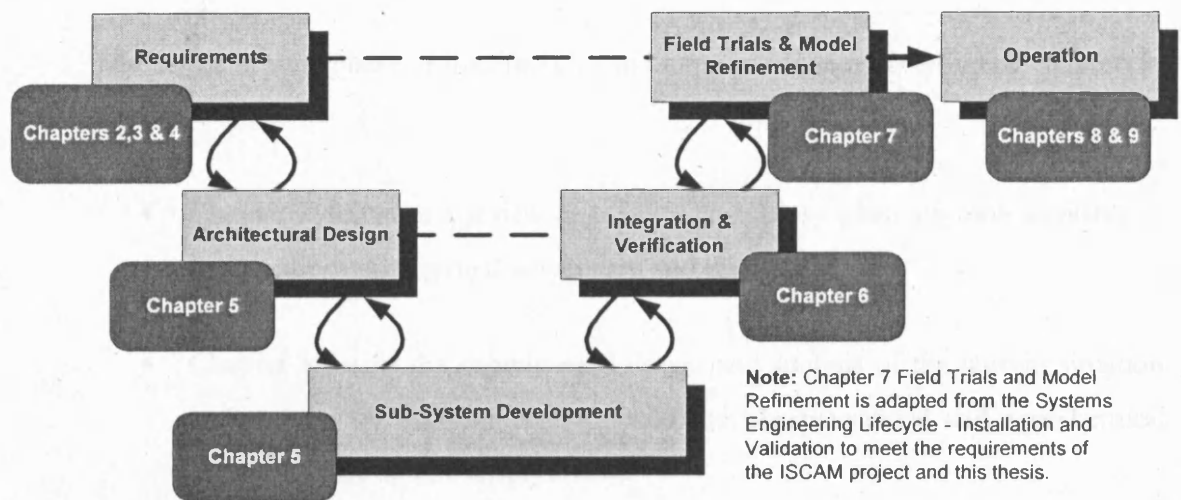


Figure 2 Adapted Systems Engineering Lifecycle Model Based On Stevens et al (1998)

The first two research questions asked “what are the current issues being experienced within the instrumentation supply chain?” and “how are existing technology planning and management tools and processes being deployed?” and are addressed in the research results detailed in Chapter 3.

This thesis details the development of a generic adaptable technology planning and management process model and associated toolbox for the instrumentation community. The purpose of this tool is to aid the management of technology (whether it is part of an organisation’s core business or not) both internally (within the enterprise) and throughout the supply chain (extended enterprise). The process model and toolbox can also be used in a non-instrumentation context and by a range of organisations from Start-ups and Small –

Medium – Size Enterprises (SMEs) to large multinationals. In each instance the generic model will require adaptation and tailoring to suit the context.

The technology planning and management lifecycle model was developed using the following adapted Systems Engineering Lifecycle (Stevens et al, 1998), Figure 2. The lifecycle is loosely based on the ‘V’ model and depicts concurrency between the lifecycle phase (overlap between the boxes) and the connection between the front and back end activities. For example, when working on the system requirements, consideration needs to be given on how these requirements will be tested.

The details of each phase of the lifecycle can be found in the corresponding chapters in this thesis:

- Chapter 2 describes a review of existing technology planning tools available to organisations, listing their advantages and disadvantages.
- Chapter 3 details the experimental design and analysis of the current situation and technology planning issues within the pharmaceutical and agrochemical industries’ instrument supply chains.
- Chapter 4 describes the modelling of the existing tools using the Unified Modelling Language (UML). The modelling was carried out to fully understand the limitations of the existing tools and how these tools may fit together in an integrated process model. Observations made during this modelling process were added to the list of advantages and disadvantages to be addressed during the development of the technology planning process model.
- Chapter 5 details the high level architectural design and the low level sub-system development of the technology planning and management lifecycle model using UML. This included the mapping of the technology planning issues obtained from the study onto the existing range of technology tools and then ‘plugging’ any gaps between the two.

- Chapter 6 describes the integration and verification of the model by describing how the model works using a hypothetical example of a washing machine manufacturer.
- Chapter 7 details the field trials and refinement of the technology planning and management lifecycle model using field trials and a set of performance measures. The model was first tested with the Solar Physics group from University College London's (UCL) Mullard Space Science Laboratory (MSSL) to refine the model before testing it on the pharmaceutical and agrochemical organisations.
- Chapter 8 details the implementation of the Technology Planning and Management Lifecycle Model. The chapter includes a tool box of useful technology planning tools with guidance for the user.
- Chapter 9 provides the final conclusions and discussion of further work to take the model forward into a product that is useful to industry (transition into operations).

Chapter 2

2. REVIEW OF EXISTING TECHNOLOGY PLANNING AND MANAGEMENT TOOLS

This chapter provides a review of the range of technology planning and management tools that exist. A summary of their advantages and disadvantages is provided in appendix 1.

2.1 Technology Planning and Management Tool Review

The technology planning and management tool review aims to answer the “when” and “how” questions of technology. These tools can provide an indication of how to carry out technology planning and some of the results will provide the timing of “when” this should be carried out.

This review was conducted in parallel to the information gathering from the participating companies. It involved reviewing existing literature and documentation (including company documentation) and obtaining feedback from the participating companies (employee feedback) and actual company performance measurements (where these existed). The methods of obtaining employee feedback and the types of performance measures are discussed in chapter 3.

The relationship between the tools/processes and current practice within the participating companies can be compared. An assessment of each tool and process has been conducted to understand its applicability to this project.

The following review of the tools and processes was grouped by the author into the following categories (based on a simple technology planning lifecycle); Technology Planning Input, Technology Forecasting, Technology Review (internal & external), Technology Implementation (acquisition, development and continued investment), Technology Planning and Management Lifecycle. A summary table is provided in appendix 1 to outline the advantages and disadvantages to enable an easy comparison to be made. Chapter 4 explores

the modelling of these tools in UML and chapter 5 addresses how these tools can fit together within a complete Technology Planning and Management Lifecycle.

2.2 Technology Planning Input Tools

The following tools are mainly associated with providing inputs (e.g. business drivers) to the technology planning process. A wide range of other business tools, for example from marketing and corporate strategy, can be used to support this activity. Examples of such tools include SWOT (Strengths Weaknesses Opportunities and Threats) and Porter's (1979) 5 forces model.

Input tools include techniques for technical analysis of products and services that will satisfy the needs of the customer or market place. These analysis techniques include the identification of technologies required to fulfil the requirements of the product or service.

2.2.1 Attribute Analysis And Quality Function Deployment (QFD)

Attribute Analysis is where a technological phenomenon is analysed with respect to its suitability to a number of practical applications (Twiss, 1986, p75). Twiss identifies that these uses are not always immediately obvious, for example, the Flymo lawnmower or a hospital bed for burns patients are not obvious uses of the hovercraft principle.

To perform an Attribute Analysis, a list of attributes is produced and then for each attribute, a practical use is identified. Osborn (cited by Twiss, 1986, p75) suggests that the following questions should be considered during the analysis:

- How could it be put to other uses?
- How could it be Adapted?
- How could it be Modified?
- How could it be Reduced?
- How could it be Substituted?
- How could it be Rearranged?
- How could it be Reversed?
- How could it be Combined?

This method is focused on the various applications of a technology and can be both an advantage and a disadvantage. The advantage is in the provision of new uses for a given technology, however the disadvantage is that these applications may be outside the scope of the organisation's business strategy. The organisation will be looking for those technological developments that give them a competitive advantage within their industry. This method may be applied, however, to technologies deployed in other industries and an organisation may be looking to see how it can employ them within its own industry.

A similar technique, which looks at the attributes of a product, technical solutions and customer requirements, is Quality Function Deployment (QFD). QFD is widely promoted in Quality Management literature and is relatively popular, for example no trade-studies course is complete without it. QFD is a structured process where the requirements of the customer form the foundation of the process and these are used to prioritise and trade off technical solutions and product features, which are then used to drive the design of the product or service (Bossert, 1991, pp1-8).

This technique involves drawing up a matrix, see Figure 3 for the matrix structure, which is the foundation to the QFD exercise. However, it can be difficult to construct, as it requires a large amount of data from a wide variety of sources (Bossert, 1991, pp1-8).

The left side of the matrix is a list of what the customer wants from the product or service. This is not always obvious, and the elicitation of customer needs and wants is a complex and difficult process.

The top of the matrix is an outline of the organisation's requirements and can include expectations and constraints from suppliers.

The right hand side of the matrix is used for product and technology planning and indicates the importance rating, competitive analysis, target value, etc and is used to calculate a weighting factor which will help the design team focus on those functions which yield the greatest potential for success (Bossert, 1991, pp1-8).

The very top of the matrix is used to identify the organisation's trade offs.

The main body of the matrix is used to categorise the relationships, that is, translating what the customer wants into the terms of the organisation (Bossert, 1991, pp1-8).

The bottom of the matrix identifies the organisation's requirements, each with a critical success priority and a difficulty to achieve factor (Bossert, 1991, pp1-8).

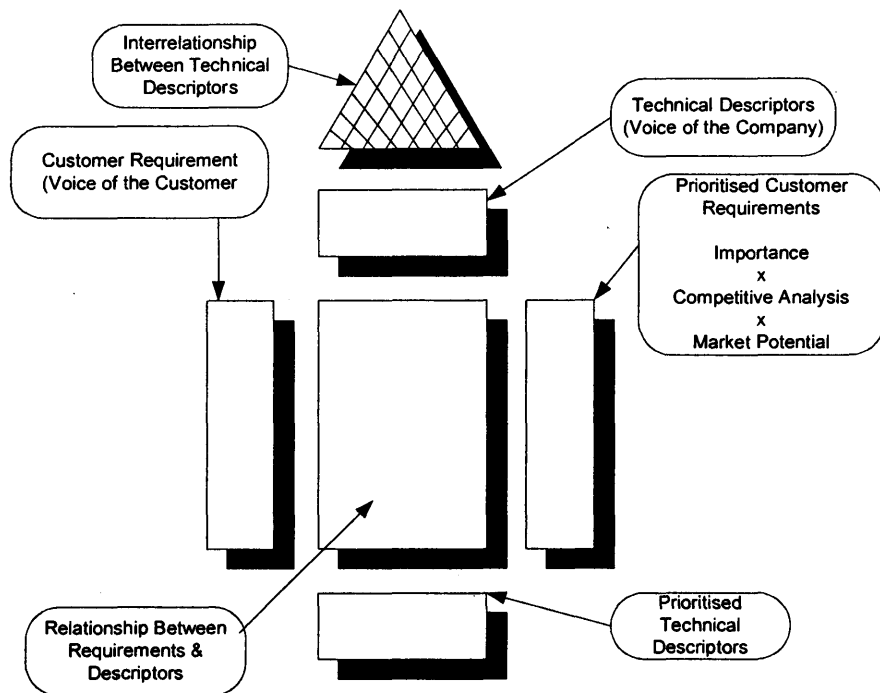


Figure 3 A Basic QFD Matrix Showing Various Components (Bossert, 1991, p7)

2.2.2 Needs Research

This is not a technology-planning tool in its own right. Twiss (1986, p76) suggests that it is an approach which promotes the elicitation, understanding and analysis of the “users” needs. This approach in systems engineering terms is “Requirements Engineering”.

Future customer requirements are identified by the Needs Research approach by using technology forecasting tools and techniques. The aim is to identify both the technical and non-technical factors (Twiss, 1986, p76). A typical needs research process would (Steiner Marketing Website, 2002):

1. Gather information from various sources. For example, user comments, customer surveys, distributors, competitors, employees and general commercial environment trends.
2. Distill the special attributes and list them without ranking.
3. The attributes are tested and ranked for importance with current and potential customers.
4. The result is a list of persuasive attributes for each target market. These persuasive attributes are then clustered to formulate an ideal product line and technology strategies.

These needs are then modelled to understand the future system performance and emergent properties. This modelling allows an organisation to determine where technological investment should be spent to obtain the most benefit, and hence added value to the customer. The result of this modelling can be used in the decision making process for defining R&D projects.

The advantage of this approach is that it provides market pull for the development of technology and ensures that the customer values the technology being invested in. The disadvantage is that it cannot be carried out in isolation, other techniques are required to deliver the forecasting and planning of the technologies that are identified.

2.2.3 Relevance Trees

Relevance Trees are used to explore the structural relationships of a product/component/system in a systematic way (Twiss, 1986, pp226-228). The starting point of a relevance tree is the top-level system to be analysed, for example, space travel to another planet or satellite. The problem is then broken down to the next level by either alternative concepts (e.g. re-usable space vehicle, once-off rocket, etc.) or by functions to be performed (e.g. launch, mid-course flight, planet/satellite landing, take-off, return course flight, re-entry and landing).

For each solution at the higher level there are a number of ways in which it may be satisfied involving a number of sub-systems. Starting with the desired result and using this approach, each path can be explored in depth, until a detailed and limited set of R & D objectives are defined (Twiss, 1986, p227).

The following example of a relevance tree diagram (Figure 4) shows how the problem of air pollution can be addressed (note for simplicity the tree is not fully complete) (example from Wiley Student Wave website, 2005). The general objective can then be explored further by breaking it down into broad alternate methods. These can then be broken down into processes and methods and so on. Hence the whole hierarchy of the general objective can be explored down to the required level.

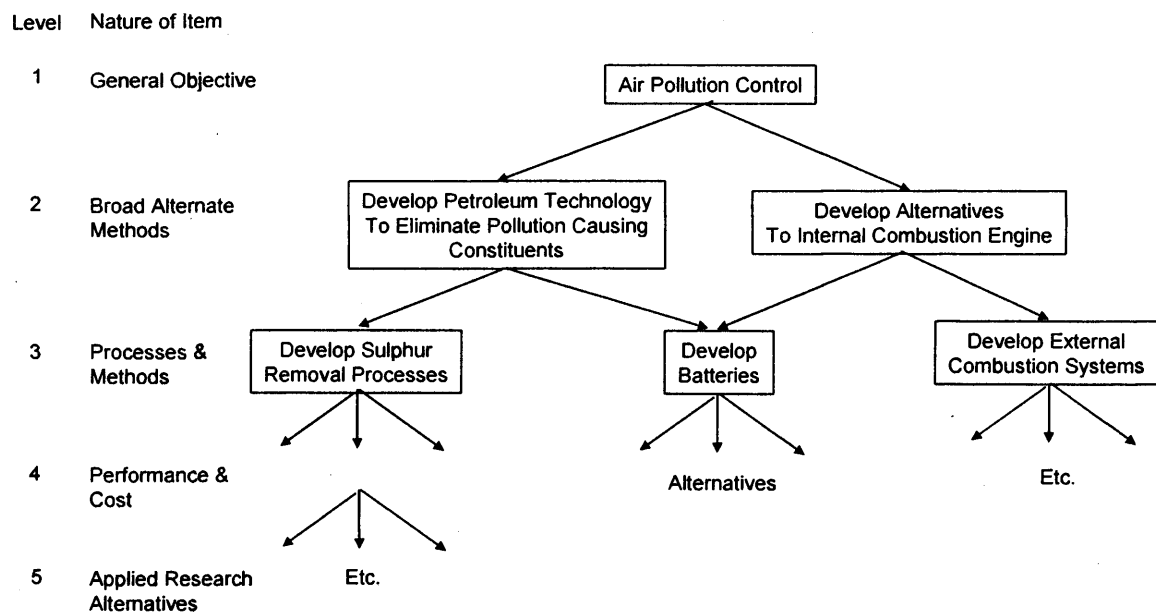


Figure 4 Air Pollution Control Relevance Tree Example
(Wiley Student Wave Website, 2005)

Cardullo (1996, p87) suggests that qualitative relevance trees can be useful in quantitative analysis and are also an aid for decision-making.

Twiss (1996, pp227-228) identifies the following advantages of relevance trees:

- Allows the feasibility of a technology to be established – if no feasible path can be found then the technological mission cannot be achieved.
- Determines the optimum R&D programme by analysing the paths through the hierarchy.
- Selection and planning of specific technology projects.
- Establishing performance objectives for the R&D programme.

- Identifying risk areas on contributing technologies where performance and time are critical – detailed technology forecasts will be required for these technologies.

The disadvantage of relevance trees is similar to the disadvantage of morphological analysis identified by Betz (1998, p177), in that it can end up being very large in order to explore all the possible iterations of all the desired features of a technical system.

The Relevance Tree approach is also used in quality improvement processes to explore the relationship between a quality characteristic and certain factors. These diagrams are known as cause-and-effect or Ishikawa diagrams (Omachonu & Ross, 1995, pp246-247). Each alternative path is evaluated for its cause and effects and aims to identify the root cause of a problem.

2.2.4 Schema and Morphological Analysis

The schema and morphology of a technical system address the logic and phenomena, respectively, of the system's technology (Betz, 1998, pp174-175). Zwicky devised this method of analysis for exploring alternative structural (morphological) configurations of a technical system (Betz, 1998, p176).

Zwicky's morphological analysis is fairly simple, starting with one configuration of a technical system and:

1. Abstracting the salient features of the technical structure.
2. Generalising on logical alternatives in each feature.
3. Taking combinations of each alternative feature to see different configurations of the system.
4. Focusing attention on technically interesting configurations.

Twiss (1986, p75) proposes that the analysis can be carried out by means of a matrix to show all the possible combinations of desired features and possible solutions. The non-feasible ones can then be discarded.

For example, Cardullo (1996, p90) demonstrates a morphological approach to an electric vehicle, which is shown in Table 1. The power source for the vehicle could be a primary or secondary battery, a fuel cell, third rail electricity contact, or magnetically induced power. This provides five alternative methods. The drive train can be direct or indirect (2

methods). The guidance mechanism provide a further 6 alternatives. The morphological analysis of the possible combinations of the power source, drive train and guidance mechanism could result in sixty potential systems (5 x 2 x 6).

Power Source	Drive Train	Guidance Mechanism
Primary Battery	Direct Motor	Driver
Fuel Cell	Indirect Motor	Towed
Secondary Battery		Guided Path
Third Rail		Satellite
Induction		Collision Avoidance
		None

Table 1 Example of Morphological Analysis of an Electric Vehicle (Cardullo, 1996, p90)

Nicholson, (cited by Twiss, 1986, p76) provides an example of where this method has been used by the UK Atomic Energy Authority. This method provides a form of solution “brainstorming”, however, it is mainly used as a review tool for design configurations and as a technique for generating new ideas for problem solving, rather than as a technology forecasting tool (Twiss, 1986, p76).

Shanklin & Ryans (1985, pp88-89) also identified that Morphological Analysis has been used by only a small number of high technology companies (approximately one in five). However, those that do use the technique, unanimously endorse its merits for stimulating new ideas.

A disadvantage of Morphological Analysis highlighted by Betz (1998, p177) is that it is very clumsy and can end up being very large in order to explore all the possible iterations of all the desired features of a technical system. Hence it is seldom used directly. However, most technology planning is based upon the concept of Morphological Analysis - looking at all of a technical system’s structural features (Betz, 1998, p177).

2.3 Technology Forecasting Tools

The following tools can be grouped together as forecasting tools. The purpose of these tools is to predict where technology is going and to stimulate innovative ideas.

2.3.1 Committees of Experts

The use of committees of experts can provide an important view of technological change and direction of progress. However, there are some drawbacks with such committees. Twiss (1986, p222) identifies the following disadvantages of committees:

- Geographical dispersal of experts.
- Availability of the experts to attend a committee meeting.
- Committee may not reach an unbiased conclusion.
- Persuasive or articulate committee members may bias the discussion and decisions.
- Position of authority and scientific reputation can bias the committee.
- The natural reluctance to publicly change a view previously strongly expressed.
- The “band-wagon” effect where individuals will not disagree with the majority view in spite of their own judgement.

There is a large amount of research surrounding the psychological behaviour of people in groups that supports the disadvantages of committees listed above. For example, Asch (1964, cited by Twiss, 1986, pp223-224) found that under group pressure an individual would accept a majority misleading wrong judgement 36.8% of the time. This compared to a wrong judgement made 1% of the time to an individual decision.

2.3.2 Complexity Theory

Complexity theory may have a lot to offer technology forecasting but has yet not been taken up to any significant degree (Cardullo, 1996, p93). Complexity theory is based on the chaos theory, which is born out of the thousands of years of human observations that small causes can have large effects and that it is hard to predict anything for certain (Petree, 2002, pp1-9). To support this, scientists had found through modelling systems like the weather, that complex behaviour could be forecast. However, the prediction of this behaviour relies heavily on the initial conditions of the linear differential equations used in the models. Hence chaos (complexity) theory was born.

Cardullo (1996, p93) believes this new concept concerning complex systems may offer a way of viewing the technology development process in a new light. For example, combining the concept of technological vectors with complexity theory to arrive at a

condition of a strange technological attractor, i.e. a technological position from which it would be difficult for an enterprise to easily change.

Complexity theory could be applied in the same way as it is applied to other complex activities, for example the weather, to try to predict various outcomes. Technology may not be very deterministic, but instead may be a neural network and require the same learning computations for prediction as supplied by artificial intelligence.

For example, non-technical environments can influence drive and steer technology developments. This situation is clearly evident in times of conflict, for example the Second World War. Technological developments in aircraft, communications, and nuclear power were accelerated during this period. How do you predict not only the developments during these periods, but these events themselves? Some form of complexity model could be used to make these predictions. It could also be used as an alternative set of tools for TRIZ etc.

Complexity theory could be used to explore the trend towards re-use versus trend toward disposable systems and 'faster, better, cheaper' impact on approach to technology (McCurdy, 2001) and the potential reject of systems that are considered just too complex to be reliable (Perrow, 1999).

2.3.3 Delphi

To overcome the disadvantages of the committee, but at the same time obtain the value of a panel of experts to predict technology trends, Helmer at the Rand Corporation developed the Delphi approach (Twiss, 1986, pp222-224). This approach uses a panel of experts, but to remove the influence of their own personalities these experts' opinions are elicited by means of a questionnaire and the experts are not aware of the identity of their fellow panel members. The Delphi procedure is conducted as follows (Twiss, 1986, p224):

1. Panel selection (this is very important to select the right experts in order to produce a valuable prediction from the exercise).
2. Questionnaires are circulated to the selected panel members to elicit their opinions.
3. The replies are collated and re-circulated with the median and interquartile range of the replies added. The panel are asked to reconsider their views and those whose replies fall outside of the interquartile range are invited to state their reasons (this may

- be due to a lack of knowledge on the topic or more importantly they may have specialist information that the other panel members do not have).
4. The next set of responses is re-circulated along with the supporting reasons for extreme positions and the panel are requested to reconsider their view.
 5. This process may continue for the number of iterations deemed necessary to clarify any issues raised.

There are still a number of disadvantages with the Delphi technique. These include:

- Panel member selection can be biased, thus not obtaining a good cross section of expert views.
- Anonymity can relieve members of accountability leading to careless responses.
- Consensus gives a conservative view of the future and hence reinforces existing paradigms.
- Offers little insight into the members' responses.
- Responses can be at best a series of guesses and the averaging of these can give a spurious sense of scientific accuracy.

An example of the output from a Delphi forecast can be seen in Figure 5. This forecast was carried out in 1968 by International Computer Ltd and predicts the trends in the use of computer systems. Although this is an old example, it helps to look at this in the context of what has happened to the use of computers in the last 30+ years to see how accurate the forecast was.

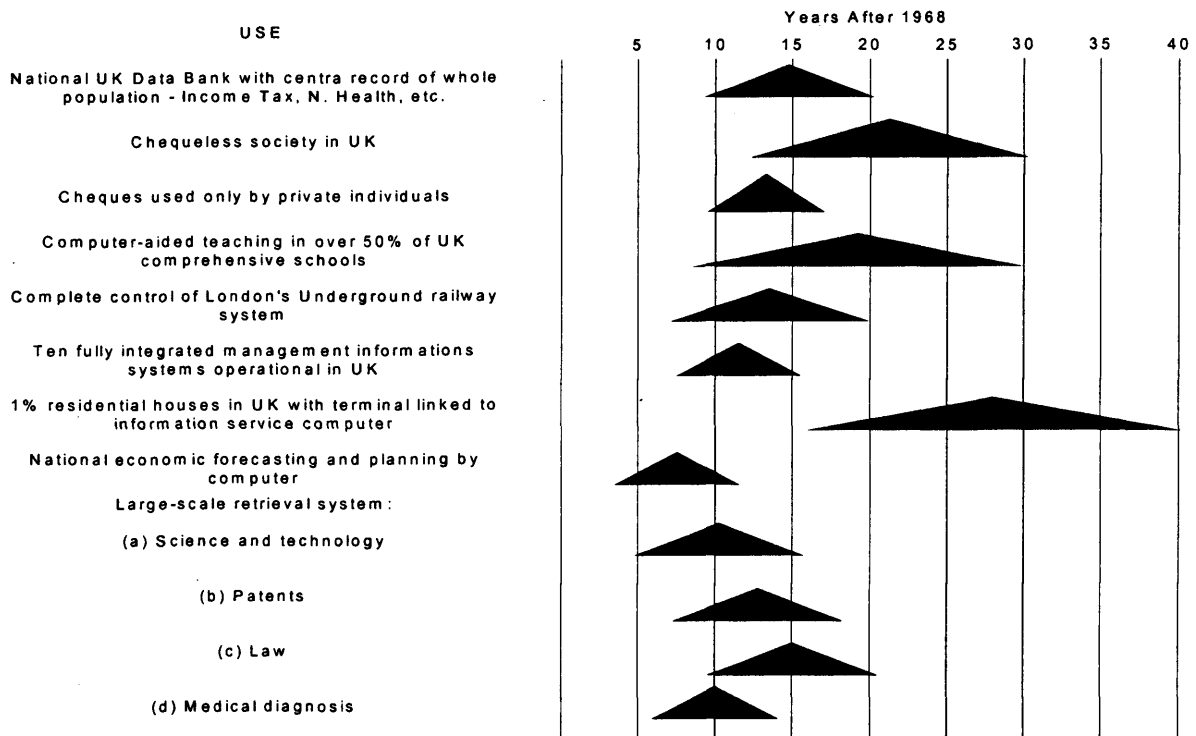


Figure 5 Part of Delphi Forecast for the Use of Computer Systems by International Computer Ltd (Hall, 1968)

2.3.4 Discrete Event Simulation

Scenarios can be "played out" by generating models in discrete event simulation software packages, of which there are a number of them on the market, for example, Simul8TM and Witness. These packages allow various processes within an organisation to be modelled and simulated to provide a visualisation of the process and or process change. The simulation can indicate bottlenecks, validate new processes, replay actions or activities, and analyse technology scenarios for decision making (Lanner Group, 2002).

For example, Lumis Corp (example from the Simul8TM website) are having problems with the length of time between customer order and delivery. They need to explore what the problems are within their processes. To investigate these problems their process has been modelled in the discrete event simulation tool, see Figure 6. The process can then be visually run to see where the problems (bottlenecks) occur, see Figure 7. Corrective action to alleviate the bottleneck can be introduced in the model to measure the potential effect. Successfully modelled interventions can then be introduced into the real process. In the Simul8TM example, an extra test station was added to alleviate the work-in-process (WIP) backlog.

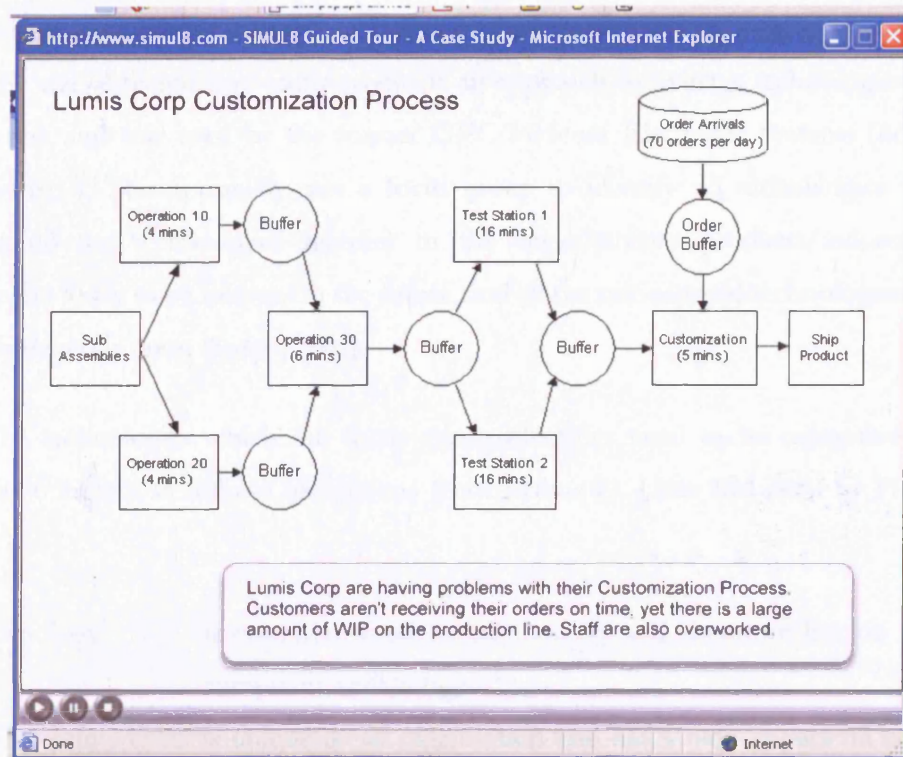


Figure 6 Discrete Event Simulation Example – Limus Corp Customisation Process (Simul8™ website, 2005)

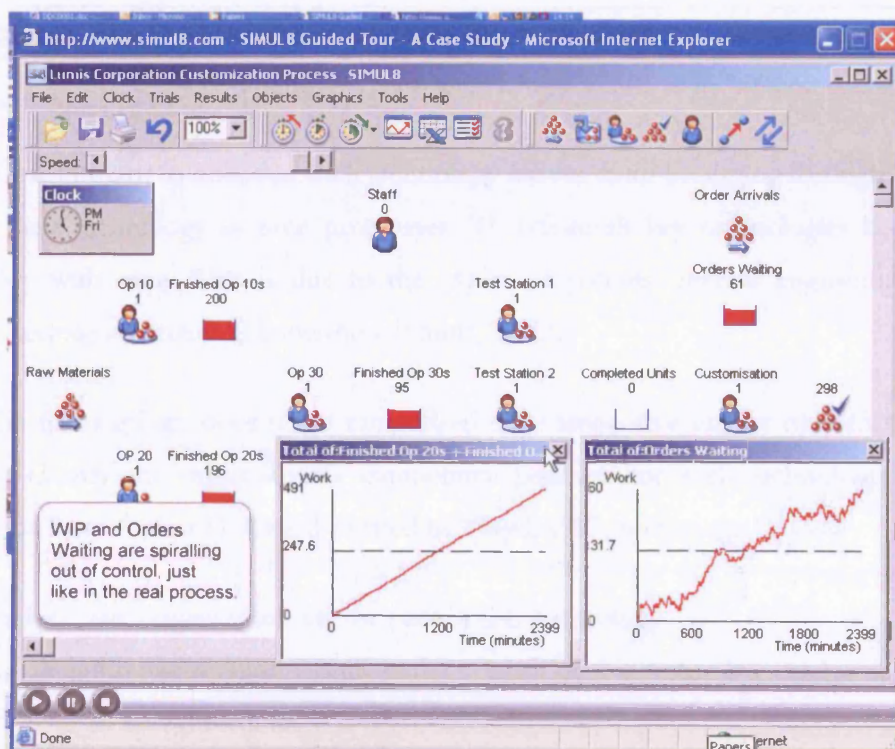


Figure 7 Discrete Event Simulation Example – Limus Corp Visualisation Of The Process Running (Simul8™ website, 2005)

2.3.5 Technology Focus Groups and Technology Footprinting

The use of technology focus groups is an approach to manage technologies within an organisation and was used by the former GEC Marconi Electronic Systems (now part of BAE Systems). This approach uses a focus group to identify: all technologies within the business, all the technologies relevant to the organisation's products/industry, all the technologies likely to be relevant in the future, and all the out-sourced technologies which the company depends upon (Smith, 2002).

The technologies which the focus group identifies need to be categorised by their competitive impact as follows (definitions from Arthur D. Little Ltd cited by Floyd, 1997, p46):

Base technology	is common to all in the industry and therefore has no impact on competitive advantage.
Key Technology	is unique to an organisation and has a high impact on competitive advantage.
Pacing Technology	is fairly new, but is likely to have a high impact on competitive advantage.
Emerging Technology	is in its infancy and has a possibility of having a high impact on competitive advantage. However, due to its infancy, it is high risk.

It is important to note that each technology moves from Emerging through Pacing and Key to Base technology as time progresses. Therefore all key technologies become base technology with time. This is due to the expiry of patents, reverse engineering and the eventual seepage of technical know-how (Smith, 2002).

The focus group, once it has categorised the competitive impact of each technology, needs to classify the organisation's competitive position for each technology as follows (definitions from Arthur D. Little Ltd cited by Floyd, 1997, p49):

Clear Leader	the organisation sets the pace in this technology.
Strong	the organisation is fully under control of this technology and is able to move in new directions.
Average	the organisation is able to sustain this technology and has niche leadership.
Tenable	the organisation is able to survive but is continually playing catch-up.

Weak the organisation is clearly behind the competitors and spends its time in a short-term fire-fighting role.

Once all the technologies have been categorised for their competitive impact and the organisation's competitive position, each technology can be plotted on a matrix to give its "technology footprint", see Figure 8 (Smith, 2001).

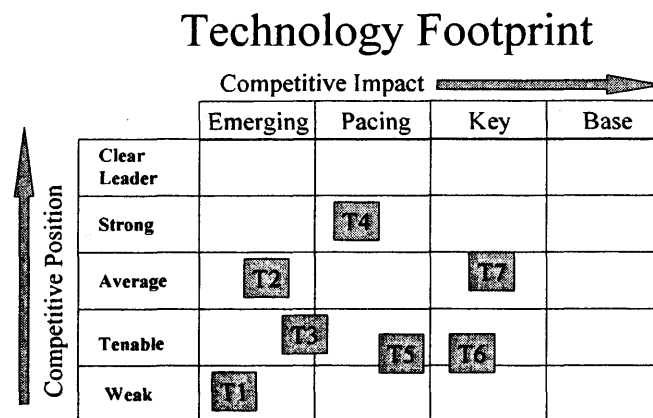


Figure 8 Technology Footprinting (Smith, 2001)

Using the technology footprint diagram Figure 8, an organisation can look to see where it needs to invest in technology. For example, if it invests heavily in emerging technologies it will have a strong lead over its competition. However, this may be high risk since not all emerging technologies may deliver a high competitive advantage or deliver at all! Investing in an average competitive position will be just enough for an organisation to keep pace with the competition. No investment will result in the organisation being out of contact with the competition in terms of the technology, see Figure 9.

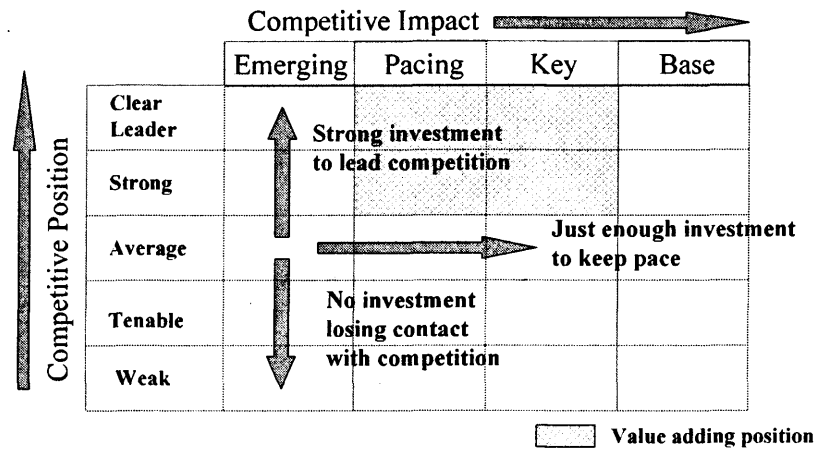


Figure 9 Technology Footprinting – Investment in Technology (1) (Smith, 2001)

An organisation could find itself investing at insufficient levels to keep pace with the competition and will fall behind. This will be particularly bad for an organisation when the technology reaches “key” status and the organisation is way behind on the development and exploitation of this technology.

The organisation should be looking to provide sufficient investment in the technology to move ahead of its competitors, see Figure 10.

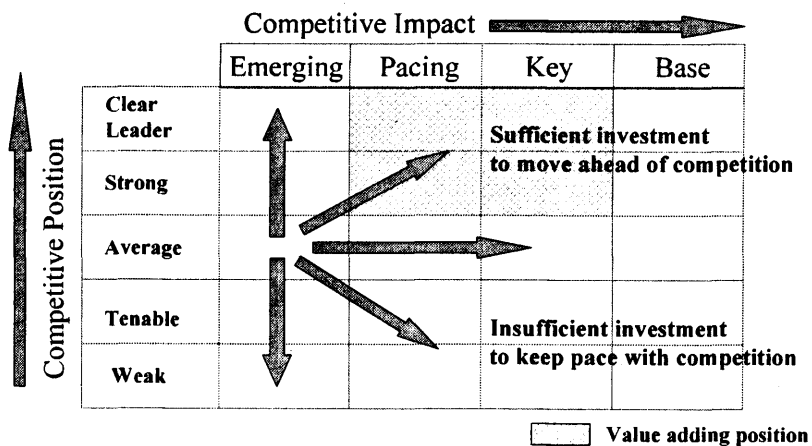


Figure 10 Technology Footprinting – Investment in Technology (2) (Smith, 2001)

Thus, the ideal profile for investing in technology is demonstrated in Figure 11.

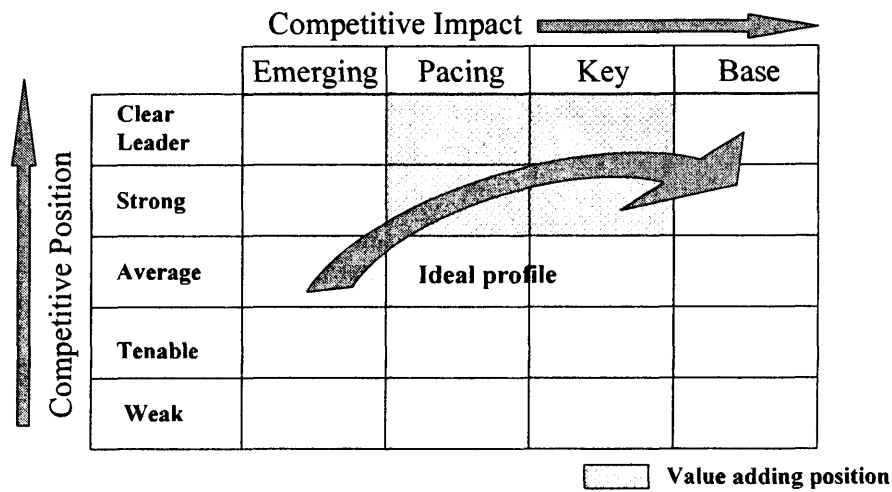


Figure 11 Technology Footprinting – Investment in Technology (3) (Smith, 2001)

Therefore, the use of technology focus groups and technology footprinting allows organisations to identify the technologies required by their industry, identify the competitive impact of these technologies, identify the organisation's competitive impact in each technology and plan for what the organisation should do to invest in each technology, see Figure 12.

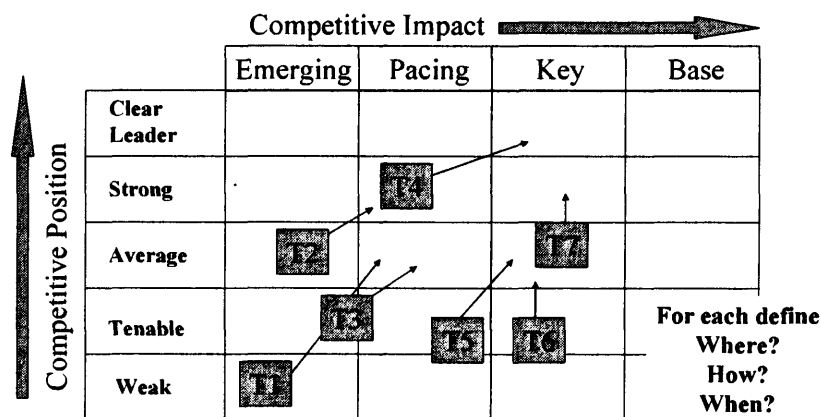


Figure 12 Technology Footprinting – Investment in Technology (4) (Smith, 2001)

These techniques are useful for positioning a technology within a market with respect to the competition. Footprinting can also hold additional information, for example the potential market size for the technology and product. The footprint can be used to define technology entry and exit strategies.

The disadvantage of this method is that it can be time consuming and requires a good knowledge of competitive technology. It also does not give any information about when and how to reposition a technology.

2.3.6 Game Theory

Game theory uses a mathematical approach to select optimum strategies from a number of scenarios. Game theory comes from a concept introduced in 1944 by John von Neumann (cited by Singh, 1997, pp166-167), who co-wrote a book on "*The Theory of Games and Economic Behaviour*". In this book von Neumann attempted to show how mathematics could describe the structure of games and how humans play them. He modelled several games like chess and poker and then went on to try to model economics. After the Second World War, von Neumann was hired by the RAND Corporation to develop Cold War strategies after they realised the potential of his ideas.

A Game is constructed from a number of game parameters that include the game structure (time & information), the number and type of players (including the strategist carrying out the technology planning) and the strategy space (the context and approach in which the game is to be played). A payoff matrix is created from the game that identifies the type of rewards for each outcome or solution for each strategy space. These solutions are then classified in terms of strictly dominant strategies (strategies that will not be optimal for a player regardless of the strategies of other players and are usually eliminated), solutions in Nash equilibrium (a solution where each player is happy to stick with their position given the positions of the other players) and solutions not in equilibrium. The final payoff matrix with the solutions classified provides a list of strategies with their corresponding outcomes which can then be used for decision making when selecting appropriate courses of action in response to the organisation's competition's strategies.

Using game theory for technology planning strategies would involve the options for technology being either in pure or mixed strategies and then applied with nature or an actual competitor as an opponent (Cardullo, 1996, p93). For example, if my competitor does X would my technology plan be better as Y or Z? The role of chance events and matrix representation of payoffs are also employed in the model. For example, if a scenario develops what are my likely payoffs from technology strategies Y or Z?

A disadvantage of game theory is that it can be difficult to establish the rules and game parameters.

2.3.7 Nominal Group Technique

Another form of committee of experts approach to technology planning, is the nominal group technique (Shanklin & Ryans, 1985, pp89-90). This also involves a highly structured approach that tempers the inordinate influence that one or more individuals could have on a group, a problem identified earlier.

The technique requires six to ten participants (or a panel of experts) to sit round a table. The problem to be tackled is then presented by the group leader. This problem is not given in detail and then without any consultation or collaboration, the group members write down their thoughts about possible solutions. By going round the table, these solutions are presented for all to see – one per person per round. During these presentations no discussions by the group is allowed.

Once all the ideas have been presented a very structured group discussion is orchestrated, allowing each individual equal time. Finally a rating or ranking procedure, where each of the group members votes confidentially, evaluates the ideas. The results are pooled and the ranking by the group forms the decision on the relative merits of each idea.

The drawbacks with this method include those already mentioned, including the availability and location of the panel of experts and the difficulties in trying to organise such a meeting. Another problem area is the skill of the group leader. This individual must be able to control the group in order to maintain the structured approach to the presentation of ideas and the following discussions.

2.3.8 Scenarios

The technology planning tools identified so far can be grouped into tools that use time series data, panels of experts, or models. Cardullo (1996, p103) identifies that scenarios are used when none of these types of tools are available to the technology forecaster, or if the forecaster is trying to integrate the results from a range of tools or is investigating a situation with a high degree of uncertainty. Scenarios also recognise that it is not always possible to choose between two alternative sets of assumptions (Twiss, 1986, p226) and one of this technique's strengths is the wide range of possible outcomes. However, in order to explore

the wide range of outcomes the number and complexity of scenarios required becomes very large and can be an effort intensive process.

Scenarios are usually prepared after a framework for the technology forecast has been established which provides (Cardullo, 1996, pp60-62):

- Technology Deployment (which technology(s)).
- Scale of Deployment (concept demonstrator or integration into full product range).
- Time from Adoption (when the technology is to be deployed in relation to the start of development).
- Critical Technology Decisions (e.g. timing, resource allocation, value).
- Timing of Critical Decisions (when do the critical decisions need to be made? eg is the decision required now or can it be deferred?).
- Who the Decision Makers Are.

The first step of preparing a scenario is to identify a sequence of events and decisions. The technology manager needs to make sure that the sequence of the events and decisions are consistent and that key decision trigger events are identified.

Once the sequences of events and decisions have been established a series of written scenarios can be prepared by describing the events (Cardullo, 1996, pp61-62). To write these scenarios, Martino (1993, cited by Cardullo, 1996, pp61-62) suggests that there are several approaches, similar to those used by authors of fictional novels. These approaches briefly are:

- Looking Backwards – the scenario is prepared from a perspective in the future by looking back towards the current position.
- Viewpoint Character – the scenario is written from the viewpoint of the individual who is seeing the event unfold.
- Gods Eye View – similar to viewpoint character, however, the perspective is more global and includes multiple perspectives. (Note: the disadvantage of this scenario is that it is not one person seeing or telling the story and therefore can lack focus or direction.)
- Diary – or journal entries, written shortly after they happen, which produces a personal account of the events as they unfold. However, this can produce sanitised events.

One of the disadvantages of scenarios is that it can produce more unrealistic results than useful ones (Cardullo, 1996, p103). This is due to the difficulty in selecting the right uncertainty factors in the scenario.

Twiss (1986, pp226-227) diagrammatically illustrates, see Figure 13, how scenarios can be used in technology decision-making. Futures A, B and C are three technology scenario directions which an organisation may take. The forecast may result in the company making one of the two following policy decisions:

Policy 1 where future A is deemed to be so probable that decisions regarding R & D are made assuming the forecast is correct.

Policy 2 is a minimum risk policy permitting progress to time T without precluding any of the three scenarios. At time T a decision cannot be deferred any longer and therefore this policy is delaying the decision to the latest possible date.

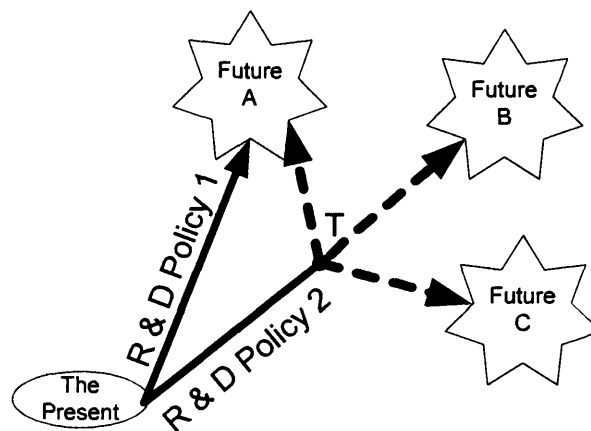


Figure 13 Example of Two Policy Decisions Made Using Scenarios
(Twiss, 1986, p227)

2.3.9 Technology Trend Models - Technology S Curve

Developments in a technology are usually to improve technical performance and therefore increase usefulness of the technology (Betz, 1998, p163). These development trends can be modelled to enable managers and developers of technology to understand and predict the rate of change of the particular technology in order to answer the questions –

“When will new technologies become available?” and “How can you influence their development?”.

A typical basic model of incremental development assumes that incremental information depends only on: the number of investigators, a recognised upper growth limit, a communications factor that depends solely on the number of investigators (Jantsch, 1967, p145). The simple model Jantsch (1967, p145) uses, models the information gained, based on the above assumptions, to give:

$$I = \frac{qN_0^2 (e^{2t} - 1)}{4c}$$

where

I = information (state of knowledge)

t = time

q = average productivity factor per investigator and time unit

N_0 = number of investigators engaged at time $t = 0$

c = coefficient (slope of curve in logarithmic plot)

This equation gives the relationship of the general rise of the total scientific and technical knowledge. However, this equation does not include the point of inflection as the technology tends towards its natural limit. Other models include the natural limit of the technology, for example the Gompertz, Pearl-Reed and Fisher-Pry curves (Mignogna, 2001). The Pearl-Reed curve is symmetrical about its point of inflection, whilst the Gompertz curve is not. The Gompertz curve also does not plot as a straight line on semilog paper. The Fisher-Pry curve is based on the sigmoidal relationship between time and the replacement of an existing technology. The choice of curve depends on the underlying dynamics of the technology development process being modelled.

This rate of change of technological development can be plotted over time and typically has a pattern that follows a “lazy” S, see Figure 14.

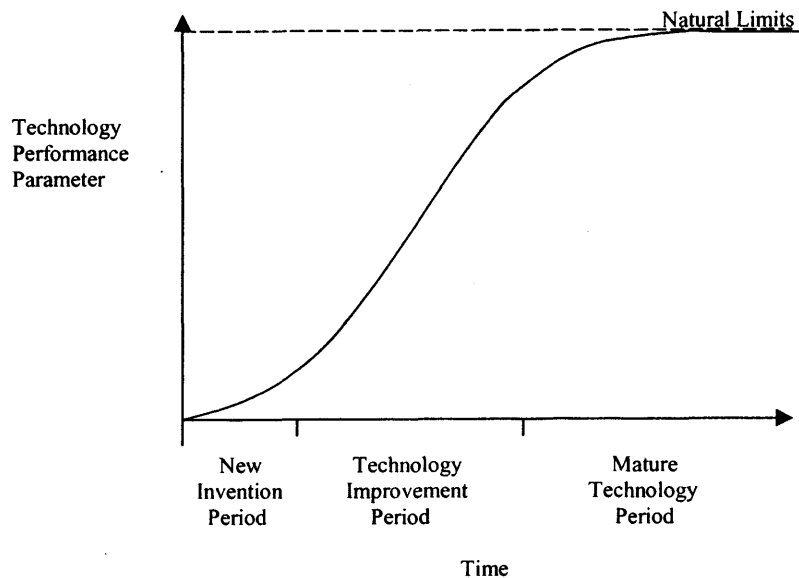


Figure 14 Technology S Curve (Betz, 1998, p164)

Considering the curve in Figure 14, the development in the technology starts with an initial exponential growth as rapid improvements are made to the “raw” science. This phase is followed by a linear progression as obvious ideas “dry up” and further progress becomes harder. Finally, the progress asymptotically levels off to little or no progress as the natural limits of the technology are reached.

Betz (1998, pp166-169) identifies two ways in which technology can change; by a change in the natural phenomena underlying a technology, and a change in the inventive logic of a technology. These changes are not mutually exclusive.

The change in the natural phenomena is where the base technology uses a different natural science, for example, the change from incandescent lamps to fluorescent lamps as a means of obtaining a brighter light. An example of a change in the inventive logic of a technology would be the introduction of integrated circuits (IC) in order to reduce circuit size. The concept still used silicon transistors, as with circuits using discrete components, however the change in the technology logic was to include other circuit elements (resistors and capacitors) also made of silicon and contained within the same device to reduce size.

The S curve can be used for technology forecasting by using it to extrapolate technical progress. The two points of inflection will need to be determined by understanding when the trial-and-error process of invention ends and also what the natural limit of the technology is (Betz, 1998, pp170). The first point of inflection is very difficult to predict and usually forecasters try to work out what the natural limit of the technology will be. This involves having a detailed understanding of the science base of the technology being forecast and relies heavily on the quantitative modelling of this science base. This normally involves a technology manager relying on consulting the scientific research community for this detailed knowledge.

An example of how trend models can be used for technology investment decisions can be seen in Figure 15. The emerging technology 2 is likely to replace existing technology 1, due to its higher natural limit of performance. The questions are when will it replace 1 what effect will it have on the investment in 1 and how are these two related? At UCL's Mullard Space Science Laboratory they use the S curve to spot technologies that will no longer be seen to be competitive and so they need to start the development of new technologies early enough. For instance they have just begun a MEMS development of electron analysers because they believe the existing large scale versions are not going to yield the desired level of performance, even though this technology continues to be selected for missions. However, it is predicted that this technology will be required as Scientists and space agencies expect ever increasing performance from their instruments.

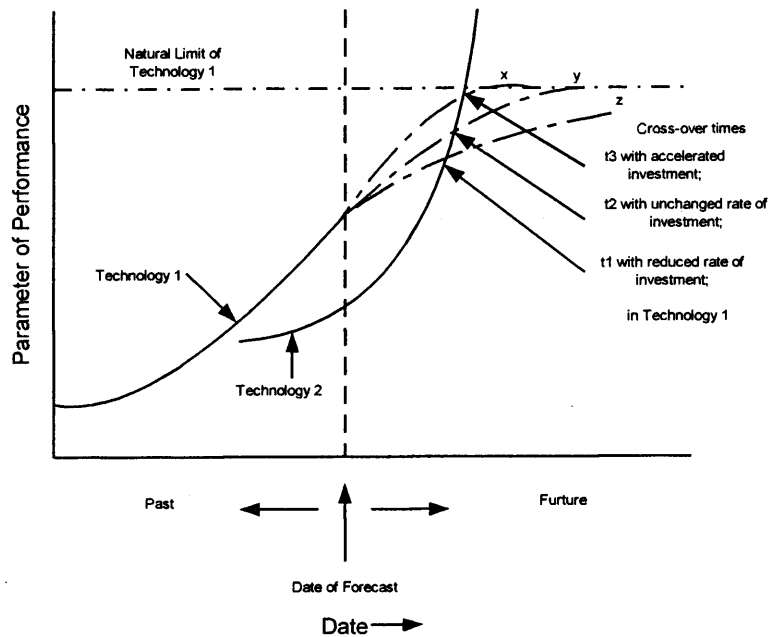


Figure 15 Effect of an Emergent New Technology on an Established Technology

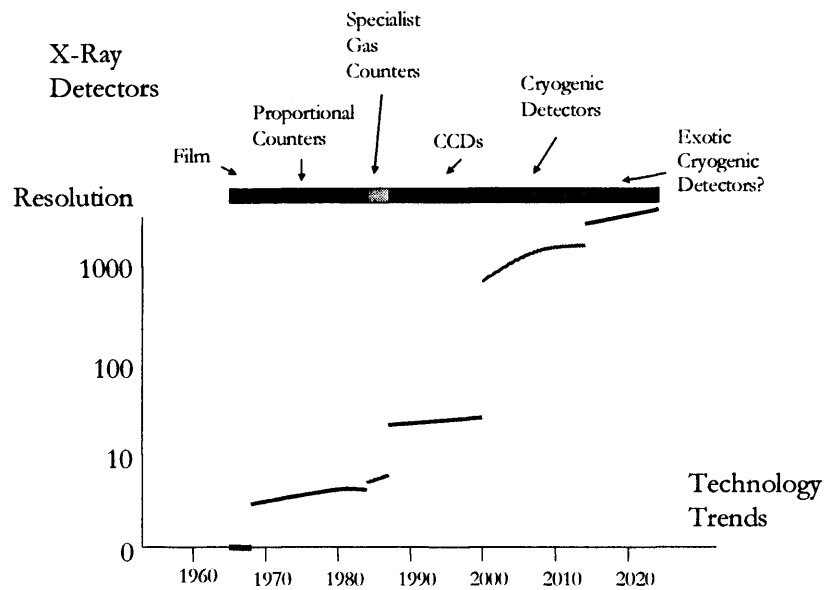


Figure 16 Technology Trends for X Ray Detectors (Smith, 2001)

Figure 16 shows the technology changes in detecting x-rays in space applications (Smith, 2001) with respect to performance in the resolution of the detector and time. This

demonstrates how one technology replaces another and the challenge for organisations is choosing when to switch.

Technology forecasting provides a tool for estimating the rate of technological change and for the identification of intrinsic factors that will limit the technology. However, it does not indicate the direction of change and it does not provide the strategy for how an organisation should influence that technological change.

2.3.10 TRIZ

Altshuller (1998, pp11-21) analysed the effectiveness of over 400,000 engineering patents world-wide. The conclusion he drew from this work was that “the evolution of all technical systems is governed by objective laws” – the law of ideality and the law of contradiction (Shulyak, 1998, p15).

The law of ideality states that throughout the life of a system it will become more reliable, smaller in size, simple – more ideal (Shulyak, 1998, p16).

Altshuller’s contraction states that contradiction “occurs when we are trying to improve one characteristic, or parameter, of a technical system and cause another characteristic, or parameter, of the system to deteriorate” (Shulyak, 1998, p17). This leads to a compromise solution being sought.

These laws govern that “*during the evolution of a technical system, improvement of any part of that system having reached its pinnacle of functional performance will lead to conflict with another part. This conflict will lead to the eventual improvement of the less evolved part*” (Shulyak, 1998, p15). The result of this is a self-sustaining process that pushes the system ever closer to its “perfect” state.

These observations laid the foundations to TRIZ, the Russian acronym for Teorija Rezhenija Izobretatelskih Zadach, Altshuller’s theory of inventive problem solving. Altshuller, and others who followed in his footsteps, have developed TRIZ over the last forty years into a set of practical tools for inventing and technical problem solving, making up what the community of TRIZ followers refer to as “systematic innovation” (Shulyak, 1998, p15).

TRIZ has become an algorithmic approach for solving problems of a technical nature (TRIZ web site, 2000). The aim of TRIZ is for engineers, planners and managers to be able to:

- Visualise the “system” from new perspectives
- Reveal all possible solution concepts
- Seek IDEAL solutions
- Develop superior products by overcoming system contradictions
- Predict future product and technical evolution
- Establish an ABSOLUTE competitive edge.

Some of the foundation concepts of TRIZ include:

- Technical Systems
- Levels of Innovation
- Law of Ideality
- Contradictions
- Evolution of Technical Systems

TRIZ uses the concept of a hierarchy of systems. That is, each system can be considered as being made up from a number of sub-systems and each sub-system is made up of a number of sub-sub-systems etc. (Stevens et al, 1998, pp302-304). The division of a system can occur until the simplest technical system is achieved, i.e. two elements with energy passing from one element to the other (Shulyak, 1998, p16).

Altshuller’s study into technical patents revealed that not every invention is equal in its inventive value. Altshuller classified the inventive value of the innovation contained in the patents into 5 levels, which range from a simple improvement of a technical system to the discovery of a new phenomenon (Shulyak, 1998, p16). Altshuller concluded that level 1 is not really innovative and that levels 2 and 3 solve contradictions in the system and are therefore innovative by definition. He also found that the majority of patents (77%) were only delivering level 1 and 2 on his innovation scale (Shulyak, 1998, p16). Altshuller’s development of TRIZ led him to believe that if it is used in practice it is capable of helping inventors elevate their innovative solutions to levels 3 and 4.

The evolution of a technical system occurs along eight patterns or lines, according to Altshuller. These patterns are:

- Lifecycle
- Dynamization
- Multiplication cycle
- Transition from macro to micro level
- Synchronisation
- Scaling up or down
- Uneven development of parts
- Replacement of human (Automation)

Altshuller (1998, pp23-103) identifies 40 principles, which are TRIZ keys to technical innovation. A summary of these can be found in appendix 2. Shulyak (1998, pp107-108) proposes a three-step process that can be used to solve innovative problems that contain a technical contradiction and uses Altshuller's 40 principles:

Step 1 – Analyse the technical system

Step 2 – State the technical contradiction

Step 3 – Resolve the technical contradiction

Others have also developed similar processes for using TRIZ, for example Rantanen and Domb (2002) have a five step process:

Step 1 – Clarify the trade off behind the process by describing elements in the system as tool and object pairs with an action that links them.

Step 2 – Define and explore the inherent contradiction behind the trade off.

Step 3 – Map resources in the system (mainly seeking invisible resources).

Step 4 – Increase ideality of the system (increase benefits/reduce cost/reduce harm).

Step 5 – Evaluate solutions.

To resolve the technical contradiction a matrix is utilised to remove the contradiction. This matrix (Webb, 2002, p122) lists 39 characteristics of a technical system (see appendix 3) that can be improved against the same 39 characteristics that can get worse. The matrix is used to identify the most appropriate of the 40 principles that can resolve the conflict between the two parameters of the system. For example, to resolve the contradiction between an improvement in the weight of a mobile object against degrading the strength of an object, the principles of (see appendix 3 for contradiction matrix and appendix 2 for the principles):

18. Mechanical Vibration

- a. Utilise oscillation.
- b. If oscillation exists, increase its frequency to ultrasonic.
- c. Use the frequency of resonance.
- d. Replace mechanical vibrations with piezo-vibrations.
- e. Use ultrasonic vibrations in conjunction with an electromagnetic field.

27. Dispose

- a. Replace an expensive object with a cheap one, compromising other properties (i.e. longevity).

28. Replacement of Mechanical System

- a. Replace a mechanical system with an optical, acoustical, thermal or olfactory system.
- b. Use an electric, magnetic or electromagnetic field to interact with an object.
- c. Replace electric, magnetic or electromagnetic fields that are:
 - 1. Stationary with mobile.
 - 2. Fixed with changing in time.
 - 3. Random with structured.
- d. Use fields in conjunction with ferromagnetic particles.

40. Composite Materials

- a. Replace homogeneous materials with composite ones.

The author has some reservations about the characteristics identified within the matrix and this list is probably not exhaustive. In addition, due to its focus on physical contradictions, applying the contradiction matrix to software appears to be difficult. These

reservations are shared by Webb (2002, p124), who points out that the TRIZ contradiction matrix does not address powerful innovation stimulants such as economics and energy substitution. This may be due to TRIZ being developed under a non-capitalist regime where economic pressures were very different.

However, TRIZ does look like a useful tool in assisting with the thought process of breaking down problems into their component parts and taking a holistic, system-of-systems view of the problem. However, the author can envisage instances when substantial abstractions are required before the principles can be applied. This is due to the physical nature of the principles and the fact that some higher level abstractions may not fit comfortably into these detailed physical properties.

Schulz, Clausing, Fricke, and Negele (2000, p199) cite the following example of how the principles of TRIZ can be applied. Boeing resolved a typical systems conflict whilst designing the 777 (fig. 737) propulsion system nacelle that uses the TRIZ principles of conflict resolution. In order to reduce the direct operating costs of the aircraft by using only two jet engines, the diameter of these engines needed to be increased to ensure enough air throughput was provided to generate the required amount of thrust. These engines are mounted underneath the aircraft's wings and as a result of this increased nacelle diameter the engines became dangerously close to the ground, hence leading to a conflict between two engineering parameters: the diameter of the engines and the distance between the nacelle and the ground.

Using the TRIZ principle 4 "Asymmetry", (see appendix 2) to resolve the conflict between parameter 4 "length of a stationary object" and parameter 8 "volume of a stationary object" (see appendix 3), Boeing flattened the bottom of the nacelle keeping the diameter and cross-section but increasing the ground clearance.

Another area of weakness is that the principles of TRIZ are based on a review of filed patents at a given point in time. The value of the TRIZ principles will diminish with time. For example, the TRIZ principles are very mechanically orientated and Webb (2002, p124) points out that "Fields" (e.g. ultrasonic, magnetic, electric) tend to replace mechanical systems as they mature.

This then leads to the question of who is going to conduct a review of current patents to provide an update to the principles? Webb (2002, p124) suggests that TRIZ practitioners in the US are already beginning to wonder what will replace it? and are proposing new creative techniques and ways forward.

2.4 Technology Review (Internal & External) Tools

The tools in this section enable organisations to review how good they are at particular technologies, how good their competition is and how good best practice is. These tools can be used to establish a capability starting point for an organisation wishing to improve its capability and also can facilitate the monitoring of progress.

2.4.1 Technology Audit

Managers must conceptualise technology, as they normally bundle useful technologies together rather than the individual technologies themselves (Ford & Saren, 1996, p55). For example, a simple electric hand drill is based on the product technologies of motor design, plastics and metal alloys. It also rests on the process technologies of armature winding, plastic extrusion automated assembly, etc. A tool that can assist in this conceptualisation of technology is a technology audit (Ford & Saren, 1996, p55).

Technology audits also aim to explore the organisation's ability to successfully develop and introduce new technology into the organisation (Cardullo, 1996, p263). These audits may also reveal the requirement for additional forecasting and capability studies, for example benchmarking.

An audit aims to identify a company's capability in the area being audited against some form of reference or standard (Vorley, 1996, p107). It may be difficult to define a "technology reference" or "technology standard" against which an organisation can audit.

Ford & Saren (1996, p59) suggest that a technology audit should aim to answer the following questions:

- What technologies does the company possess?
- Where did these technologies come from?
- What is the range of our technologies?

- What categories do our technologies fit into?
- What is our standing in our technologies?
- What is the life-cycle position of our technologies?
- What is our performance in acquiring technologies?
- What is our performance in exploiting technologies?
- What is our performance in managing technology?

An example of a technology audit is given in Figure 17. This audit was conducted on the product and process technologies of a food ingredients company who make a wide range of food additives, which add flavour, colour and texture (Ford & Saren, 1996, pp85-86). Each technology was defined as being either basic (industry wide knowledge) or distinctive (compared to competitors). Further analysis produced the figures in the matrix, which indicated that two-thirds of the company's gross contribution came from areas where it has no distinctiveness from its competitors.

The company believed that most of its activities drifted into cell 1 as their technologies lost their competitiveness. Cell 1 activities produce a lower percentage gross margin per unit sales, as they are essentially commodity products that are available from a large number of suppliers. This analysis resulted in the company re-assessing its whole business strategy and investment in technology and has led them to seek a more balanced approach to the different areas.

		Product Technologies	
		Basic	Distinctive
Process Technologies	Basic	Cell 1 66% e.g. Sausage Seasoning	Cell 2 19% e.g. Snack Foods Seasoning
	Distinctive	Cell 3 1% e.g. Emulsifiers	Cell 4 13% e.g. Textured Gluten for Vegetarian Prepared Foods

The percentage figures refer to the proportion of the company's total gross profit contribution generated from each technology.

Figure 17 Example of a Technology Audit - The Contribution of Different Product and Process Technologies (Ford & Saren, 1996, p86)

2.4.2 Technology Benchmarking

Technology Benchmarking, like other forms of benchmarking, is where an organisation performs a direct comparison of the performance of its technology base with other organisations in a similar field (Cardullo, 1996, p259). These organisations can be competitors or those who are deemed to be the “best” or “world class” in specific technical areas. In order to compare differences between the organisations, it is important that technology metrics are identified to facilitate the comparison.

Benchmarking is more than a means of gathering data on how well a company performs against others; its objective is process improvement (Omachonu & Ross, 1995, pp140-142). This improvement should meet both strategic and operational needs of the organisation. Omachonu & Ross (1995, pp140-142) identify three benefits of benchmarking:

1. Cultural Change – being able to set realistic and rigorous new targets.
2. Performance Improvement – identifying and defining specific gaps in the company's performance.

3. Human Resources – provides a basis for identifying gaps between an individual's skills and world class and can provide a basis for training.

Camp (1989, cited by Cardullo, 1996, p259) suggests a ten-step process for benchmarking as follows:

1. Identification of metrics.
2. Identification of comparative organisations.
3. Establish method of data collection.
4. Analysis of current performance differences.
5. Forecast future performance levels.
6. Report findings.
7. Define the organisation's functional goals.
8. Develop an action plan to improve performance with respect to world class.
9. Implement and monitor plan.
10. Recalibrate benchmarks to determine if improvement has been achieved.

Benchmarking can be very useful, however, it can be difficult to identify organisations that are world class in a specific technical area (Cardullo, 1996, p260) and in addition it is also difficult to define what "world class" is. Cooper and Kleinschmidt (1995, cited by Cardullo, 1996, p260) identify a number of barriers to benchmarking, which are:

- Time to carry out the benchmarking process.
- Co-operation of other organisations to obtain comparison data.
- Organisation's experience in the benchmarking process.
- Identification of the link between best practices and improved performance, due to unknown underlying factors.

Another pitfall of benchmarking identified by Omachonu & Ross (1995, pp152-153) is the level of employee involvement. Poor involvement may become a barrier to the benefits identified earlier. Employees need to be included in the process as they will benefit from the benchmarking data gathered, e.g they will benefit from identifying skills gaps they might have, and they have to "buy-in" to improving the deficiencies identified.

The definition of the process to be benchmarked needs to be carried out before data is gathered; otherwise there is a danger that the benchmarking will not be a means to process improvement, but rather an end in itself (Omachonu & Ross, 1995, pp152-153).

An example of how benchmarking has been used to improve an organisation's capability comes from Rank Xerox (DTI, Nov 1994 cited by Ho, 1995, p117). Due to its problems in the late 1970's and the expiry of its photocopying patents, Rank Xerox's market share had halved by 1980. The company decided to benchmark the way its photocopiers were made. It compared its organisation's functions against 3M in Dusseldorf, Ford in Cologne, Sainsbury in Hertfordshire, Volvo in Gothenburg and IBM's international and French warehouses. Xerox measured the gap between themselves and best practice. For example, Xerox identified that information from the field was important to the way they conducted business and the benchmarking identified that it took an extra day for this information to reach their centre compared to best practice and therefore they needed to update and improve their information systems.

2.4.3 Technology Monitoring

The majority of creative ideas come from the combination of pieces of knowledge that have relevance to the problem being solved. Therefore, the larger amount of knowledge that is available, the more creative ideas could theoretically be achieved (Twiss, 1986, p78). Technology Monitoring, or technology awareness, provides a systematic gathering and processing of information from a wide range of sources. Its aim is to direct focus to where a new development and existing knowledge can provide a possible innovation. Twiss (1986, p78) identifies that technology monitoring can produce a random association of facts that would not normally occur within a formal planning framework.

Technology monitoring can be a valuable source of innovation. However, the data gathered alone cannot solely provide the innovation: it needs to be integrated with the people, with the creative ideas and some of the other technology forecasting tools.

2.5 Technology Implementation (Acquisition, Development & Continued Investment Tools)

The only tool identified for aiding the implementation of technology plans is the NASA Technology Readiness Levels. This area is not very well addressed by the current available technology planning tools.

2.5.1 Technology Readiness Levels

The maturity of a technology can be assessed by using Technology Readiness Levels (TRLs) which is a systematic metric/measurement system that allows not only the technology's maturity to be quantified, but also allows comparison of maturity between different technology types (Mankins, 1995, p1). This process, up until 1995, had been used on and off by NASA in space technology planning. In 1995 it was incorporated into a NASA Management Instruction for more widespread and consistent use (Mankins, 1995, p1).

Technology Readiness is made up of nine different levels, which describe the maturity of the technology being assessed. These levels can be summarised (Mankins, 1995, p1) as follows (see also Figure 18):

- TRL1** Basic principles observed and reported.
- TRL2** Technology concept and/or application formulated.
- TRL3** Analytical and experimental critical function and/or characteristic proof-of-concept.
- TRL4** Component and/or breadboard validation in laboratory environment.
- TRL5** Component and/or breadboard validation in relevant environment.
- TRL6** System/subsystem model or prototype demonstration in a relevant environment (ground or space).
- TRL7** System prototype demonstration in a space environment.
- TRL8** Actual system completed and "flight qualified" through test and demonstration (ground or space).
- TRL9** Actual system "flight proven" through successful mission operations

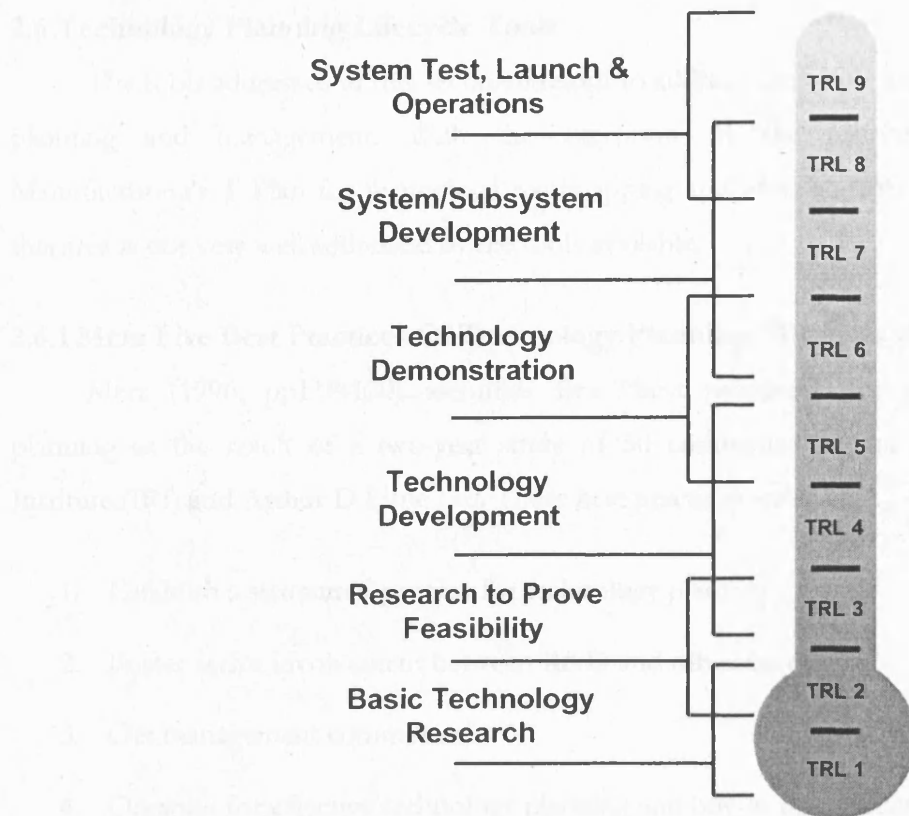


Figure 18 Technology Readiness Levels (NASA Website, 2002)

A detailed description of each technology readiness level is given by Mankins (1995, pp2-5) in his NASA White Paper.

One disadvantage of the Technology Readiness Levels approach is that it focuses on maturity in terms of investment against NASA's systems lifecycle. Mankins (1998, p1) proposes that a complementary measure of how much difficulty is likely to be encountered in the development of a particular technology needs to be added to the existing TRLs. There may well be other measures for comparison that other organisations using this method of technology classification wish to add.

The NASA definitions can easily be adapted to other circumstances and so are useful outside the space sector. For example, the UK Ministry of Defence use TRLs to help determine technical risk to their major equipment programmes. However, they need to be used with caution since a high TRL may neglect a change in context of a new implementation which can lead to a major problem down stream (e.g. Ariane V).

2.6 Technology Planning Lifecycle Tools

The tools addressed in this section attempt to address the whole lifecycle of technology planning and management. With the exception of the Cambridge Institute for Manufacturing's T Plan for technology roadmapping and Metz's (1996) five best practices, this area is not very well addressed by the tools available.

2.6.1 Metz Five Best Practices Of Technology Planning/Business Planning

Metz (1996, pp118-120) identifies five "best practices" for technology/business planning as the result of a two-year study of 50 companies by the Industrial Research Institute (IRI) and Arthur D Little Ltd. These best practices are:

1. Establish a structured process for technology planning.
2. Foster active involvement between R&D and other functions.
3. Get management commitment.
4. Organise for effective technology planning and buy-in by all functions.
5. Hold business units and R& D accountable for measurable results.

Metz (1996, pp118-119) had observed different approaches to establishing a structured process for technology planning. There was a critical element, however, which was to establish a structure as a foundation to the planning process. Metz (1996, pp118-119) found that this structure involved common steps as depicted in Figure 19.

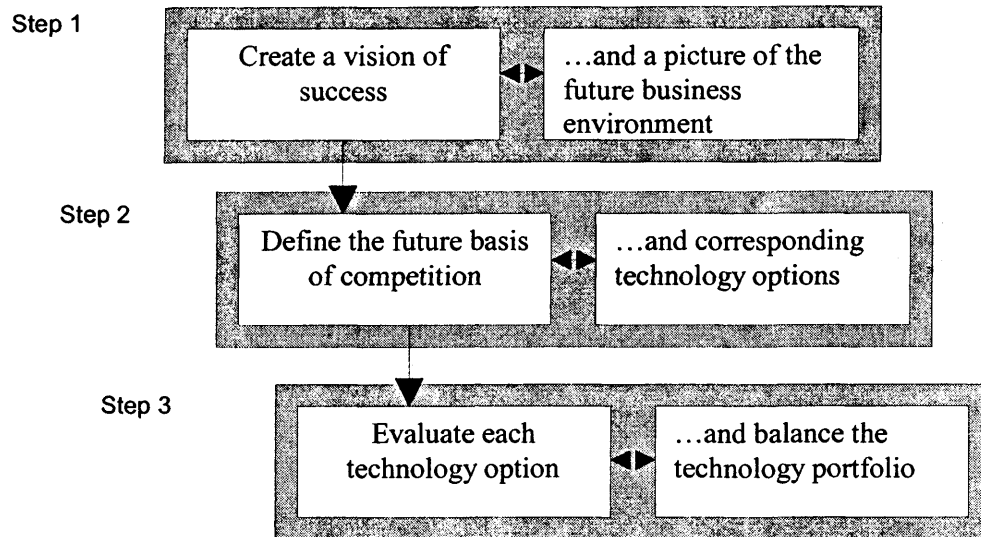


Figure 19 Establishing a Structured Technology Planning Process is the First "Best Practice" (Metz, 1996, p119)

The fostering of involvement between R&D and other functions is aimed at a cross-functional approach to the technology planning process. This involvement operates at two levels: a managerial level to communicate the needs and goals of the business to R&D, and a team level to prioritise projects for development.

Management commitment is fundamental to all business activities. Without it the right resources, direction and motivation cannot be mustered. Crosby (cited by Omachonu & Ross, 1995, p10) identified management commitment as being key to the implementation of corporate initiatives. For example, he listed management commitment as the first of his fourteen points of Total Quality Management (TQM).

Technology planning will also need the same managerial drive and muscle behind it. Technology planning needs to address the long-term as well as the short-term objectives of the business and company managers need to understand and support the technology plan (Metz, 1996, p119).

Organising for effective technology planning and buy-in by all functions is an extension of the fostering of involvement between R&D and the other organisational

functions. This can be achieved by organising the company so that its structure can support effective technology planning.

Holding business units and R&D accountable for measurable results aims to establish an internal market for technology development, which is measured and is accountable for its value for money. The author has some reservations about the application of measures, in that they need to be carefully derived and implemented, as the measures themselves can provide distortion of what is important to the business and stifle development. In essence “you are what you measure”.

Metz provides a high level view of the traits of best practice for technology development based on research. However, there is no detail about how these best practices are implemented.

2.6.2 Technology Roadmapping

The use of the Technology Roadmapping technique is growing within industry to support the development, communication and implementation of business and technology strategy (Phaal et al, Nov 2001, p1). This technique generally takes the form of multi-layered time-based charts linking future markets and products with technology developments (Institute for Manufacturing, 2002, p1). It is also a very flexible technique and can be used to plan for product development, service and capability development, strategic development, long range business development, knowledge development, programme development, process development and integration (Phaal et al, Nov 2001, pp5-8).

For example, space scientists use instrumentation onboard satellites to conduct experiments to gather more data and knowledge about the universe. One such space borne experiment uses x-ray detection equipment. This equipment has had various technologies employed each giving a better resolution of detection. Roadmapping can be used to track these developments, see Figure 20.

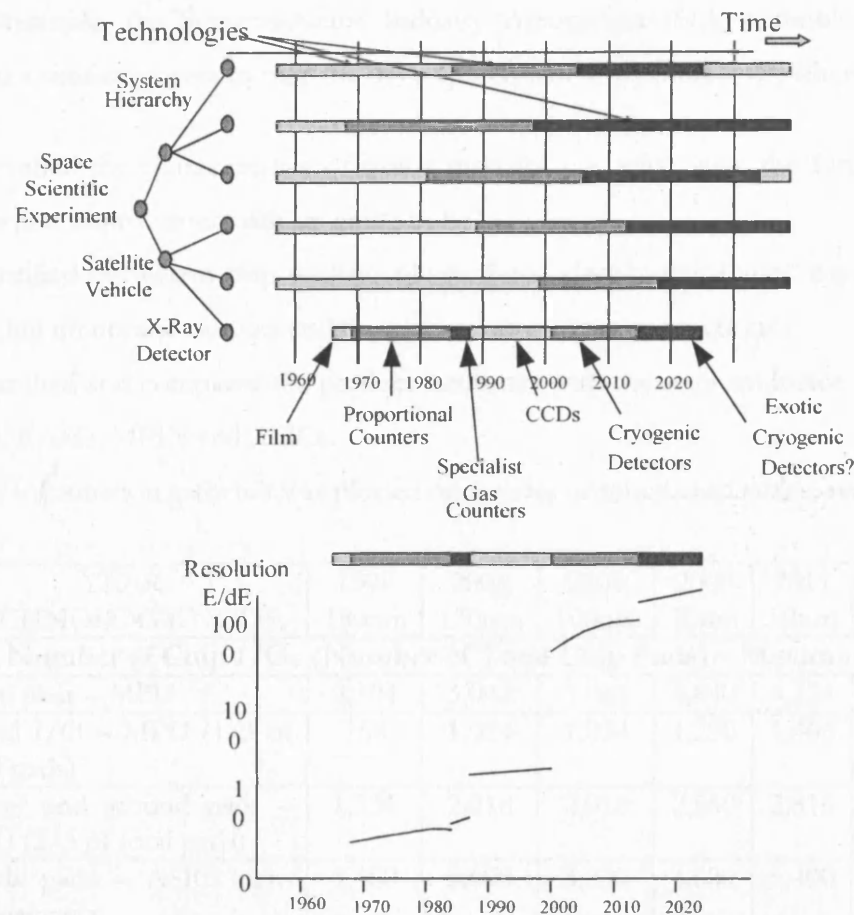


Figure 20 Example Of Technology Roadmap Of X Ray Detectors (based on Smith, 2002)

There are various approaches to this technique and a number of ways the information can be illustrated, for example, tables, graphs, flowcharts, etc. (Phaal et al Nov 2001, pp8-10). However, the issue facing organisations and individual managers, is how to initiate the process for the first time and how to sustain it once it has been started (Phaal et al, 2001, piii).

To tackle these issues, the Cambridge Institute for Manufacturing have developed an approach based on research conducted in UK industry. This approach, known as the T-Plan process, involves a series of four facilitated workshops (Phaal et al, 2001, piii):

1. Identification of market and business drivers.
2. Generation of product feature concepts.
3. Identification of technology solution options.
4. Charting of milestones, product and technology evolution.

For example, the Semiconductor Industry Association (SIA) technology roadmap (1999), used a similar process to map the developments of semiconductors, where they:

1. Identified the characteristics of major markets, e.g. what were the future cost-per-function improvement drivers going to be?
2. Identified the silicon chip package physical and electrical attributes, e.g. the number of chip inputs and outputs and the physical size of the connections.
3. Identified and compared the product attributes with the semiconductor technologies of DRAMs, MPUs and ASICs.
4. The information gathered was plotted on a series of time-based tables, see Table 2.

YEAR TECHNOLOGY NODE	1999 180nm	2002 130nm	2005 100nm	2008 70nm	2011 50nm	2014 35nm
Number of Chip I/Os (Number of Total Chip Pads) – Maximum						
Total pads – MPU	2,304	3,042	3,042	3,840	4,224	4,416
Signal I/O – MPU (1/3 of total pads)	768	1,024	1,024	1,280	1,408	1,472
Power and ground pads – MPU (2/3 of total pads)	1,536	2,018	2,018	2,560	2,816	2,944
Totals pads – ASIC high-performance	1,400	2,600	3,800	4,600	5,400	6,000
Signal I/O pads – ASIC high performance (1/2 of total pads)	700	1,300	1,900	2,300	2,700	3,000
Power and ground pads – ASIC high-performance (1/2 of total pads)	700	1,300	1,900	2,300	2,700	3,000
Chip-to-package pads (Peripheral)	368	464	584	736	927	1,167
Number of Total Package Pins/Balls-Maximum						
Microprocessor/controller, cost-performance	740	1,012	1,384	1,893	2,589	3,541
ASIC (high-performance)	1,600	2,248	3,158	4,437	6,234	8,758

Table 2 Semiconductor Industry Association Technology Roadmap (1999) Example – Based on Tables 3a and 3b Performance of Packaged Chips: Number of Pads and Pins

In the author's review of several example technology roadmaps, it is the author's opinion that roadmapping provides a simple diagrammatic view of future plans and a summary of what is going to happen and when. The roadmap also helps to avoid writing off ideas just because they are not technically feasible today. However, most of the maps

reviewed by the author did not show the next level of detail, are difficult to keep up to date and have no measure of realism in their timescales. In addition, there is no scale or weighting used to allow for a comparison between technologies and there is no costing element to the map.

Roadmapping is also a difficult concept that can get very complex very fast (point also made during the study conducted into the instrumentation supply chains of the pharmaceutical and agrochemical industries, see chapter 3). Using the 80-20 rule (the first 20% of effort produces 80% of the benefit) is important in order to stop at the right point when the most value can be gained. Engineers may feel that since the process is imperfect, it is not valuable and therefore there can be a tendency for a perpetual request for data.

The technology roadmapping process is similar to the focus group and technology footprinting, described earlier.

2.7 Summary Of Existing Technology Planning Tools Review

This review of the existing tools and processes has grouped them into the following categories (based on a basic technology planning lifecycle):

Technology Planning Input

- Attribute Analysis & Quality Function Deployment
- Needs Research
- Relevance Trees
- Schema & Morphological Analysis

Technology Forecasting

- Committees of Experts
- Complexity Theory
- Delphi
- Discrete Event Simulation
- Technology Focus Groups & Technology Footprinting
- Game Theory
- Nominal Group Technique

- Scenarios
- Technology Trend Models – Technology S Curve
- TRIZ

Technology Review (internal & external)

- Technology Audit
- Technology Benchmarking
- Technology Monitoring

Technology Implementation (acquisition, development and continued investment)

- Technology Readiness Levels

Technology Planning and Management Lifecycle.

- Metz Five Best Practices of Technology & Business Planning
- Technology Roadmapping

Not all the technology planning lifecycle groups are well served by the existing range of tools. This will be explored further in chapter 5 which addresses how these tools can fit together within a complete Technology Planning and Management Lifecycle.

Chapter 4 explores the modelling of these tools in UML and the methods of obtaining employee feedback and the types of performance measurements are discussed in chapter 3. Chapter 3 describes the study of current situation within the pharmaceutical and agrochemical industries' instrumentation supply chains and the issues affecting technology management.

Chapter 3

3. STUDY OF CURRENT SITUATION WITHIN THE PHARMACEUTICAL AND AGROCHEMICAL INDUSTRIES' SUPPLY CHAINS

Having established what technology planning and management tools are available, this chapter details the study conducted into the current situation regarding the 'What, When, Why, Who, Where and How' of technology planning and management within the pharmaceutical and agrochemical industries' instrumentation supply chain. The study design was based upon research literature, best practice and a series of issues from the participating organisation's experiences and outputs from the DTI Intersect Faraday Partnership meetings (the Intersect Faraday Partnership is managed by Sira and NPL). The findings from the study are also detailed in this chapter and used in chapter 5 to aid the development of the technology planning and management lifecycle model.

3.1 Empirical Case Study Research Design

The design of the empirical case study research was based on the following [experimental] design steps (Miller, 1984, pp152-158):

1. Conceptualisation of the problem
2. Research design
3. Operationalising the case study [experiment]
4. Analysis and interpretation of results.

3.1.1 Conceptualisation Of The Problem

The case study explored a large pharmaceutical company's research and development use of instrumentation and a large agrochemical company's end users' use of instrumentation. The study also explored the associated supporting supply chains. The purpose of the case study was to gather information by exploring the relationships that exist and the technology planning and management issues associated with procuring the "right" instrumentation, at the "right" time and at the "right" price.

Conceptualising the problem and the formulation of the research questions were developed from some of the perceived issues that were discussed by the participating organisations. These issues were highlighted at a project progress meeting held at UCL on 11th December 2001 that was attended by Dr John Gilby (Sira), Dr Paula Knee (NPL), Dr Bruce Grieve (Syngenta), Dr Ian Hughes (GSK), Prof Alan Smith (UCL), Dr Michael Emes (UCL) and the author (see appendix 4 for the notes of this meeting). The issues raised were based on general experience from the meeting attendees and from outputs from DTI Intersect Faraday Partnership and included:

- Vendor competition and market control
- Technology push
- Technology misuse
- User buy-in
- Cost of ownership
- Lifecycle mismatch
- Interface compatibility and profusion of standards
- Compatibility with bespoke systems
- Influence
- Impact on bottom line
- Where does technology bite?

3.1.2 Research Design

3.1.2.1 Information Gathering Process

In order to obtain the data required from the case study, the following information review and gathering process was formulated, see Figure 21:

1. Information definition - what information is required from the participating companies by the project?
2. Literature review of data collection methods – what methods are available to obtain the different types of data? What tools are available to process each data type?
3. Review of best practice – which of the tools and methods are appropriate and what is best practice?

4. Implement method of information elicitation, collation and analysis.

During the course of the study there were several iterations through the four steps. The data was elicited in the form of qualitative information as the issues of technology planning and management within the supply chain were explored and defined from both a user's and supplier's perspective. This type of data can be extracted using techniques like participant observation or interviews, which allows an open-ended process of enquiry to explore these issues and allows the project team to home in on the real issues for investigation within the context of the project (Jorgensen, 1989, pp12-34). These identified issues can then be tested and explored with more qualitative methods.

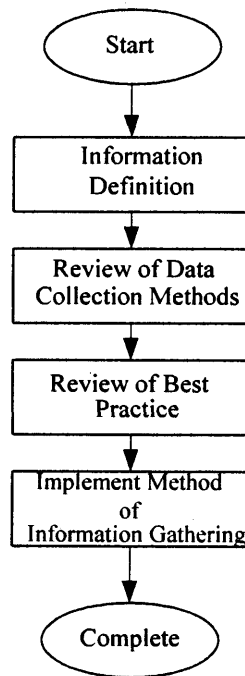


Figure 21 Information Gathering Process

The last stage of implementing the method is part of operationalizing the experiment and will be discussed later.

3.1.2.2 Information Definition

The first part of the information gathering process is to understand and define what information is required by the project during each phase. This information was used to

develop the business and technology planning and management models and was also used to conduct preliminary validation of these models.

In addition, information was gathered on issues associated with technology planning and management in the instrument supply chain and how these affect the output variables of that chain. Some issues have already been identified from the project progress meeting held at UCL on 11th December 2001 (for minutes see appendix 4).

The qualitative field interview notes required interpreting, using various techniques (Feldman, 1995, pp1-21). For example, Semiotic Analysis, which is “the study of the signs or systems of signs [and it] concerns the principles by which signification occurs. Signification refers both to the processes by which events, words, behaviours and objects carry meaning for the members of a given community and to the content they convey” (Barley, 1983, p394).

3.1.2.3 Literature Review of Data Collection Methods

A review of current elicitation techniques and data analysis tools was conducted. Morris (1996, p40) points out that the getting hold of information is rather “chicken-and-egg” in that “how you collect the information depends on what you want to do with it”. The appropriate tools and techniques were selected based upon the type of information required (e.g. quantitative or qualitative), where that information is sourced and in what form it is used by the study. Curnock (1996, pp11-13) identifies a typical study life cycle of: identifying the problem, defining the sampling frame, defining the data required to explore the problem, deciding how the data will be collected, describing and analysing the data, and drawing conclusions.

The data gathered during the study is mainly qualitative, to identify the issues regarding technology planning and management. Mile & Huberman (1994, p1) point out that qualitative data can provide a good source of data, which is well grounded, rich in descriptions, and explanations of processes in identifiable local contexts. It also provides an insight into the kind of issues organisations have when dealing with the instrumentation supply chain. The research questions for the study were explored using a case study approach. Using a case study research strategy the research questions took the form of ‘how’ and ‘why’ (see Table 3) Yin (1994, pp5-9).

Strategy	Form of Research Question	Requires Control Over Behavioural Events?	Focuses On Contemporary Events?
Experiment	How, Why	Yes	Yes
Survey	Who, What, Where, How Many, How Much	No	Yes
Archival Analysis	Who, What, Where, How Many, How Much	No	Yes/No
History	How, Why	No	No
Case Study	How, Why	No	Yes

Table 3 - Relevant Situations for Different Research Strategies (Yin, 1994, p6)

The data gathering was conducted through structured interviews. The interviews were conducted with customers, suppliers and users of instrumentation to get a rounded picture. This approach helped avoid taking what was discussed at face value. This was a criticism made by one of the project's sponsors about the data gathered as part of an investigation into "Changing Practice in the UK Domestic Supply Chain for Instrumentation" (Sira & NPL, 1999, pp8-34). Part of the interviewer's role is to establish what is actually happening as opposed to what the interviewee says is happening as these may be completely different. This was an issue encountered during one of the interviews. The interviewee was giving the author the answers he believed were required rather than what was actually happening. These answers were re-evaluated using perspectives from other interviewees from the supply chain.

The use of focus groups was considered and despite several advantages, for example, by the participants interacting with each other to articulate their thoughts and feelings (Stewart & Shamdasani, 1990, pp9-50), it was considered that to organise the minimum requirement of six people for a focus group (Stewart & Shamdasani, 1990, pp57) at each participating company would be very difficult. The use of a questionnaire was also considered. This was ruled out, however, as it was felt that subjects may not be sufficiently motivated to respond by just a covering letter and a set of instructions (Hoinville, 1977, p125). The relatively small sample size also made questionnaires unattractive.

Jorgensen (1989, pp82-95) describes a number of ways in which data may be gathered through participant observation: Observation whilst participating, Interviewing, Documents and Human Artefacts, and Personal Experience. All these ways are used during the process of performing a quality audit, for example.

To conduct the interviews, the right organisations and the right people within those organisations were identified by the two sponsoring organisation's whose supply chains were being studied. This selection was made once the project had established which part of the value chains were to be explored. For example, for organisation 1 this was the R&D use of instrumentation and for organisation 2 this was the end users of their products. The organisations who should be approached were suggested by the sponsoring organisation. The criteria for who should be interviewed was based on exploring, where possible, the technology planning and management issues across all the functions of the business (e.g. marketing, support, engineering, etc). The interviewees included: senior management, field sales engineers, chemists, technicians, farmers, agronomists, engineers, levy bodies, government agents, sales and marketing, etc. The numbers of interviewees available to the study varied depending on the size of the organisation and staff availability.

The interview questions were tailored towards the interviewee's position within the organisation to elicit an informed response from them. In addition, a conscious effort was made to avoid judgemental responses that are difficult to define (Birnbaum, 1998, pp1-3). For example, the judgment of how much someone "likes" using an instrument or instrumentation system is difficult to quantify, especially when comparing it to another person's response.

Each interview followed a structured plan that involved informing the interviewees what subjects were to be covered, explaining what would be done with the data gathered, obtaining consent to put the data onto a database (to comply with the Data Protection Act, 1998), undertaking the interview, following-up by e-mail to clarify any loose ends and to agree the interview transcript report. The following sections provide more details on the interview design.

3.1.2.4 Review of Best Practice

Various texts on the methods of data gathering have been reviewed, see reference list, to provide guidance on good practice. Recent research that had been conducted using the data gathering methods of case studies and structured interviews was reviewed. In particular it was used to elicit data in a similar field (software systems engineering) to establish issues like requirements traceability (Gotel OC Z & Finkelstein A C W, 1996) and process technology implications of procurement processes (Ellmer E, Emmerich W & Finkelstein A, 1998).

To support the review of best practice, meetings were arranged with some of the individuals who conducted this research to discuss their experiences regarding the use of structured interviews and their experiences in evaluation in software engineering (Farbey B & Finkelstein A, 2001). The aim of the meetings was to explore what worked well and what didn't work so well and why? In particular, advice was sought on how long to conduct the interview, how to make the interviewee at ease to elicit as much of the required information as possible and to avoid the introduction of bias. Advice was also sought into the planning of the interview format. Particular points to note were:

- Establish a rapport with the interviewee by being polite, explaining what you are going to do and ask if it is okay to follow up with a brief transcript of the points discussed for clarification
- Use positive body language
- Show interest in the interviewee
- Keep the interview to time
- Keep the interviewees on track and try to keep wandering off at a tangent to a minimum
- If possible use a recording medium to supplement notes.

To assist with the design of the interview, a pilot study was conducted at Sira Ltd, see section 3.1.3.5, to obtain feedback on its suitability for the project. Pilot studies have been used successfully to identify and address any problems in advance with research projects (Cowper, 1997, p48).

3.1.3 Operationalising The Case Study

This part of the process utilises the review and selection of the information gathering tools and techniques. The tools, for example interview questions etc., have been designed according to guidance from best practice. The plan for the information gathering needed to be implemented. For example, interviews had to be structured, planned and conducted in a way to minimise the distortion and bias to the results. Yin (1994, p20) identifies five important components of a case study:

1. a study's questions,
2. its propositions, if any,
3. its unit(s) of analysis,
4. the logic linking the data to the propositions, and
5. the criteria for interpreting the findings.

The areas of the instrumentation supply chain that this study focused on were discussed during a project progress meeting held on the 8th March 2002 that was attended by Dr John Gilby (Sira), Dr Paula Knee (NPL), Dr Bruce Grieve (Syngenta), Dr Ian Hughes (GSK), Prof Alan Smith (UCL), Dr Michael Emes (UCL) and the author, see appendix 4. The three possible areas where instrumentation is used were; the up-front research and development of the organisation, the manufacturing process, and the final user of the product. The meeting agreed that there is already a large amount of work in the area of manufacturing. Thus, the manufacturing process is not a focus for this study; however, the links to the process both from the R & D aspect and to the final user need to be understood and will be the work of associated studies.

The study focused on the R & D use of instrumentation at organisation 1 in their High Throughput Chemistry Lab and their work on "Lab-on-a-chip". The study also addressed the final user of instrumentation in organisation 2's precision agriculture business. Precision agriculture's aim is to provide more targeted crop applications by using yield mapping and remote sensing to identify where the variations in crop health are on fields and then use this information to provide targeted treatments to these areas. This will require a high degree of sophisticated instrumentation and will provide organisation 2 with all kinds of systems integration issues.

3.1.3.1 Research Questions and Propositions

In order to establish what the current situation is regarding technology planning and management within the two organisations' supply chain is, how effective it is and what value it has three research questions were posed. For each question a series of propositions were derived from the discussions at the project review meetings of 11th December 2001 and 8th March 2002 attended by Dr John Gilby (Sira), Dr Paula Knee (NPL), Dr Bruce Grieve (Syngenta), Dr Ian Hughes (GSK), Prof Alan Smith (UCL), Dr Michael Emes (UCL) and the author. The issues from these meetings, listed in section 3.1.1, can be grouped with each research question as follows:

- Issues associated with how technology is currently used within the instrumentation supply chains (Technology push, user buy-in, influence, technology misuse, interface compatibility and profusion of standards, and compatibility with bespoke systems)
- Issues associated with the effectiveness of current technology planning and management tools and processes (Lifecycle mismatch).
- Issues associated with instrumentation value (What is the impact on the bottom line?, cost of ownership, vendor competition and market control, and where does technology bite?).

The following research questions and propositions were peer reviewed by Dr John Gilby (Sira), Dr Paula Knee (NPL), Dr Bruce Grieve (Syngenta), Dr Ian Hughes (GSK), Prof Alan Smith (UCL), and Dr Michael Emes (UCL).

Question 1 is aimed at establishing how technology planning and management is used in the two supply chains of the study:

Question 1: How is technology planning and management used in the R & D and Final User stages of the instrumentation supply chain?

Proposition 1.1 is based on comments associated with “technology push”, “user buy-in” and “influence (customer/end user)”, listed earlier in section 3.1.1:

Proposition 1.1: Customers/End Users and Final Users play a minimal part in the technology planning process within the R & D and Final User stages of

the instrumentation supply chain - leading to technology push in the instrument supply chain with minimal user buy-in and influence.

Proposition 1.2 is derived from comments associated with “technology misuse”, listed earlier in section 3.1.1:

Proposition 1.2: The full functionality of instruments is not being fully utilised leading to technology misuse within the instrumentation supply chain.

Proposition 1.3 addresses comments associated with “interface compatibility and profusion of standards” and the “compatibility with bespoke systems”, listed earlier in section 3.1.1:

Proposition 1.3: Instrumentation development is being driven by standardised interfaces and the profusion of standards making equipment compatible with bespoke systems.

Question 2 explores how effective current technology planning and management tools and processes are:

Question 2: How effective are current technology planning and management tools and processes within the instrumentation supply chain?

Proposition 2.1 is derived from discussions at the project review meetings of 11th December 2001 and 8th March 2002 and the author’s own experiences:

Proposition 2.1: Not many formal technology planning and management tools or processes exist or are used by the instrumentation supply chain leading to a lifecycle mismatch between instrumentation systems being required and instrumentation systems being available.

Question 3 is associated with establishing the value of the instrumentation to the organisation’s being studied and what contribution technology planning and management has in the project’s context:

Question 3: What effect do instruments have on Customer/End User and Final User business performance with regard to their use in R & D facilities and in providing added value to the Final User?

Proposition 3.1 addresses comments associated with “where does technology bite?” and “impact on the bottom line”, listed earlier in section 3.1.1:

Proposition 3.1: Instrumentation plays an important part of the Final User and End User/Customer’s business process; hence instrumentation has a significant contribution to organisations’ bottom line (e.g. profit).

Proposition 3.2 is derived from the comments associated with the “cost of ownership”, listed earlier in section 3.1.1:

Proposition 3.2: Organisations spend a significant amount of their turnover on the procurement and maintenance of instrumentation.

Proposition 3.3 addresses the comments associated with “vendor competition and market control”, listed earlier in section 3.1.1:

Proposition 3.3: The instrumentation supply chain is dominated by a few big supplier organisations that specify what instrumentation is available to industry, hence the vendor competition is low and market control by the suppliers is high.

3.1.3.2 Unit of Analysis

In the classic case study, a case may be an individual, for example the study of a clinical patient (Yin, 1994, p21). For this study, the unit of analysis was the participating organisation. However, each organisational case was made up of views from typically 1 to 5 individuals from within that organisation to form the “case” in terms of the supply chain. In addition, to enable the different perspectives required by the study, these organisations were classified into three categories; end users, customers and suppliers.

To analyse the impact on the technology planning model, the individual statements regarding technology planning issues became the unit of analysis.

3.1.3.3 Linking data to propositions, and criteria for interpreting the findings

There is no precisely defined science for the linking of data to the propositions and the criteria for interpreting the findings and this is an area of case studies that is the least well developed (Yin, 1994, pp25-26). However, Campbell (1975, cited by Yin, 1994, p25) used an approach for case studies involving “pattern matching”, where several pieces of information from a study are related to some proposition. A simple “eyeball” test is used to show that the actual pattern is either systematic (effects) or unsystematic (no effects) towards the proposition.

This approach also addresses the fifth component of the study, the criteria for interpreting the study’s findings. The “eyeball” test compares whether the data follows an effects or no effects pattern to either accept or reject the propositions to the research questions. However, this comparison is not made with any statistical tests, nor can it be because each data point is single value (Yin, 1994, p26). The question arises; how close is a pattern match? There is no precise way of identifying which pattern (effects or no effects) matches the closest; one only hopes there is a significant difference, which contrasts the patterns enough to interpret the results.

Due to the qualitative nature of the data captured during the interviews and the limited number of methods to process such data, the “eyeball” test method of linking the data to the propositions and the criteria for interpreting the findings was used on this case study. The approach enabled the author and his colleagues to capture experiences as they were described and distil the key issues being explored across a number of interviews.

3.1.3.4 Interview Design

The information required by the project will be from an end user, customer, and supplier perspective. Therefore the programme of interviews will need to span the different organisations that fall into each of these categories. The interview questions required tailoring for each interview to take into account the organisation’s position within the supply chain and the interviewee’s role within that organisation. For example, when interviewing an instrumentation field service engineer the questions regarding equipment support were aimed at exploring the provision of such support. However, when interviewing an end user of instrumentation the questions regarding support were aimed at exploring the quality of this

service. Therefore, each category of organisation required a different set of questions and these questions were different depending on who in the organisation was being interviewed.

An interview question check-list was developed, see appendix 5, to explore each of the research questions and more specifically the propositions. Each proposition needed to be explored in order to test the opinions of the project's sponsors with the experiences of their supply chains. For example, to test the proposition 1.1 that end users play a minimal part in the technology planning process leading to technology push, the following questions were put to the instrument suppliers and end users respectively:

“Is the end user involved with your technology planning process?”

“ Do you feel you are involved in the instrumentation suppliers' technology planning process?”

Each question in the check-list is individually referenced to a research question and a proposition. The aim of the check-list was not to provide a deterministic questioning process but more as an 'aid memoir' to the interview approach depicted in Figure 22.

These questions were re-worded during the course of the interview to remove bias and distortion, to elicit actual feelings and issues, and to follow the process described in Figure 22. Oppenheim (1992, pp128 to 130) provides a set of guidelines to “lay down some rules” on the wording of questions. These include: avoiding double-barrelled questions: avoiding proverbs, avoiding double negatives, don't know or not applicable categories, avoiding ambiguity and leading questions.

Each interview was conducted using the process shown in Figure 22

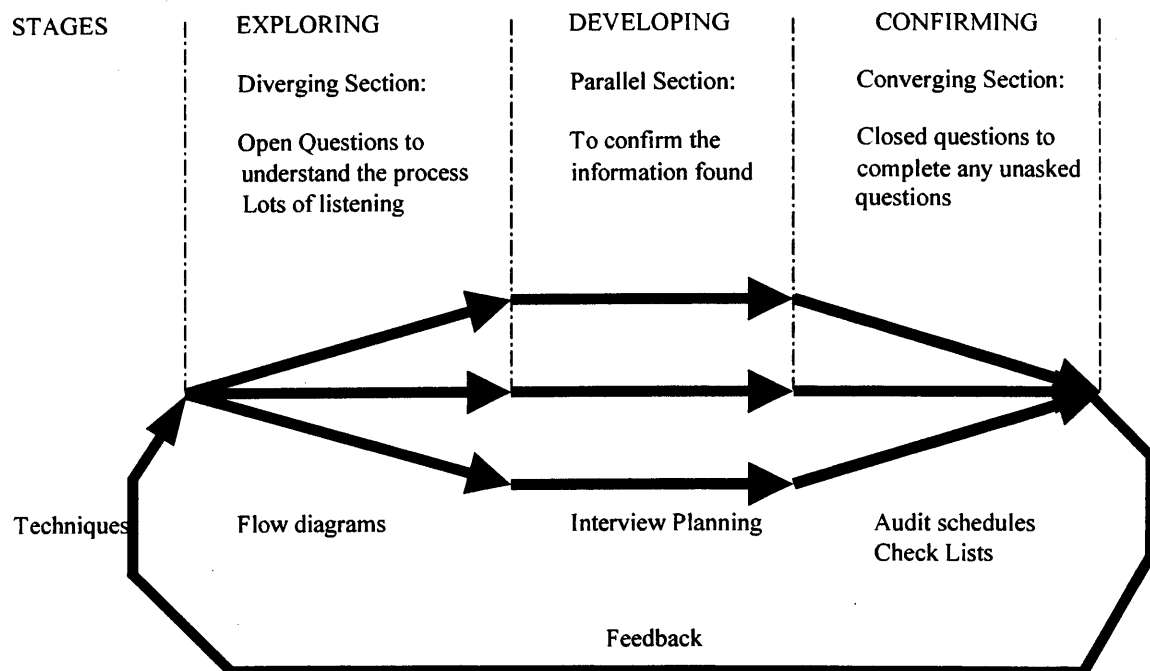


Figure 22 Interview Question Sequence based on Vorley (1996, p128)

A typical day followed the schedule detailed in Table 4:

Interview Schedule		
Time	Activity	Interviewee
9:30	Arrival	
	Walk through of company	Company Host etc.
10:00	Interview 1	MD/Senior Member of Staff
11:00	Interview 2	R&D or Product Development
12:00	Interview 3	Procurement
1:00	Lunch	Company Host
2:00	Interview 4	Sales & Marketing (Account Manager)
2:00	Interview 5	Support
3:00	Wash up meeting	Company Host
3:30	Depart	

Table 4 - Interview Schedule

3.1.3.5 Pilot Study

To test the design of the interview structure and technique, a mock interview to walk-through the list of questions was conducted at UCL followed by a pilot study conducted at SIRA Ltd.

3.1.3.5.1 Mock Interview

The aim of the mock interview was to check the interview technique, the type and number of questions and the format of the interview.

Initially, there were concerns about the number of questions to be asked, which after revision seemed to be the right amount for the hour-long interview. The mock interview highlighted the problem of trying to stick to a long list of questions but at the same time being flexible to respond and explore the interviewee's answers and in addition to make notes about these answers. It was agreed that given the number of interviewers (typically 3), it would make sense if they each had different roles to perform.

One person would be the lead interviewer who would explore the opinions of the interviewee with fairly open questions. The lead interviewer would have a check-list of topic areas to cover as a reminder to help keep the interview on track (see appendix 5). The second person would follow the interview with a list of questions, each with a given priority (see appendix 5), to check the interview is gathering all of the required data. The lead interviewer would then refer to the second interviewer who would then pick up on the unanswered questions. To limit the amount of additional questions the second interviewer would pick the top three unanswered questions.

The remaining member of the team would take notes. These notes would need to be summarised as soon as possible for circulation within the team. An amended set of notes would then be sent to the interviewee for comments and clarification. For confidentiality reasons, this summary would be sent to the interviewee only and the interviewee would be invited to make any further comments not covered by the interview.

Other comments made at the mock interview included the use of leading questions steering the interviewee for a particular answer, not enough open questions exploring the opinion of the interviewee and some questions being of a very factual nature. It was agreed that the factual information required by the modelling process could be elicited via a short questionnaire or just simply an e-mail asking for the information. The project team agreed this would be better carried out after the interview, as hopefully the team would have established a rapport with the interviewee and hence would be more likely to obtain the information required.

3.1.3.5.2 Pilot Study

The aim of the pilot study was to test the interview technique on a group of instrumentation users. The information gathered was used in the study and the interviewees provided constructive feedback on our interview approach.

The pilot study indicated that the approach developed from the mock interview worked well with one person as lead interviewer, who explores the information given by the interviewee, the second interviewer checking the topic areas covered to ensure nothing is missed and a third person taking notes. The note taker also highlighted areas of clarification, which could be covered at the end of the interview, hence reducing the need to go back to the interviewee at a later date.

The interviews conducted in the pilot study also identified a set of questions regarding component and equipment obsolescence that had not been addressed by the questions in appendix 5.

3.1.4 Analysis and Interpretation of Results

This section provides the results of the case study interviews for phase 1 of the project. Each organisation identified key individuals who would provide the project with some interesting insights and issues associated with the procurement of instrumentation. A list of key suppliers of instrumentation was also provided by the participating organisations that also provided candidates for interview.

Each interview was transcribed and returned to the interviewee to ensure they were happy with the statements. Each interview statement was loaded onto a Microsoft AccessTM database to facilitate data mining of the results. A copy of the database input page is given in appendix 6 along with the database structure.

3.1.4.1 Organisation 1

For organisation 1, forty-five one-hour interviews were conducted, sixteen of which were at the organisation and included: scientists who were end users of the equipment: internal instrument system developers and researchers: procurement personnel: and a health, safety and environment member of staff. Twenty-nine people were interviewed from ten different suppliers and included product developers, sales and marketing personnel, field service and support, and senior management.

A total of 1243 statements were loaded onto the database. Each of the research questions and associated propositions, defined earlier, were tested using a simple eyeball test (Campbell, 1975, cited by Yin, 1994, p25) against these interview statements. The purpose of the test was to see if an effects or no effects pattern existed to either accept or reject the propositions to the research questions.

The first iteration through the database reviewed the data and categorised each statement according to the list of key words in Table 5.

Background	Bespoke	Concurrent Engineering
COTS	Education/Training/Information	Effectiveness
HR Issues	Integration	Lifecycle Costs
Market Awareness	Market Pull	Procurement
Reconfiguration	Requirement/Specifications	Standards
Supplier Lock-in	Technology Management Tools	Support
Technology Push		

Table 5 Interview Statement Key Words

Each statement could be associated with up to three (one or two was found not to be enough) key words. Figure 23 shows the distribution of these statements categorised by their corresponding key words.

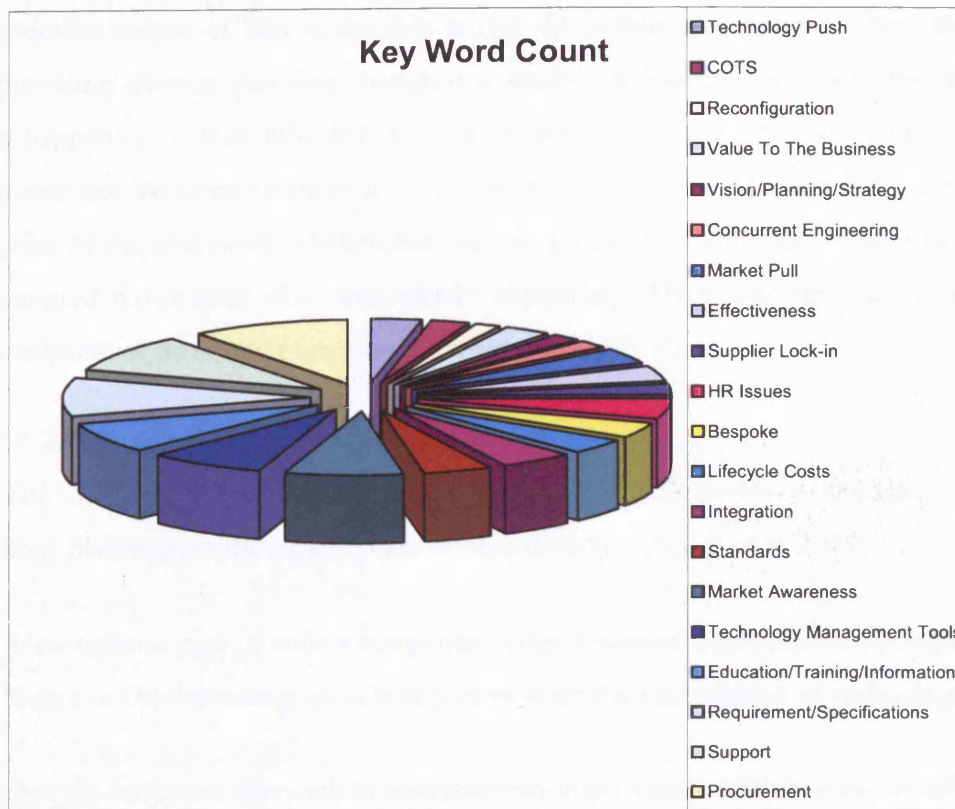


Figure 23 Distribution Of The Interview Statements By Their Corresponding Key Words

A second iteration through the statements challenged the original key word categories and re-categorised the statements into common groups of issues. The author aimed to look for the generic issue in the statement to reduce the influence of the specific situation. This second review also identified the implications for the Technology Planning and Management Lifecycle Model. A sample of the interview data and example of the reviews can be found in appendix 7.

3.1.4.1.1 Sources of Bias

A potential source of bias in processing the data, comes from the author's interpretation and categorisation of the statements into key words. Fowler (1993, pp130-131) indicates that errors introduced through the classification of answers to open questions is very small as this part of the data collection process is well controlled, especially if the researcher is working with responses to focused questions. The processing of the data included a review by a committee of academic peers to debate the interpretation of the data to reduce the amount of bias introduced by the author.

Another source of bias in the data is that the author suspects that some companies were providing answers that they thought the study was looking for rather than what was actually happening. This is difficult to test for and remove from the data as one can only deal with it once one becomes aware of it. As previously discussed this was an issue encountered during one of the interviews. The interviewee was giving the author the answers he believed were required rather than what was actually happening. These answers were re-evaluated using perspectives from other interviewees from the supply chain.

3.1.4.1.2 Testing of Research Questions and Propositions

The following observations were made from the interview statements regarding technology planning for the supply chain of organisation 1 (Smith et al, 2004):

- New technologies provide a competitive edge for many organisations. Companies may thrive or fail depending upon how they manage their acquisition of technologies.
- Any co-ordinated approach to instrumentation provision will inevitably involve a level of compromise. The natural resistance to imposition (or change per se) should be addressed explicitly, seeking user 'buy-in' where possible.
- New ideas may come from customers, suppliers, competitors and support groups and may involve adapting existing technology to new markets. Professional bodies, domain speciality clubs, trade journals and conferences may provide a forum for knowledge exchange while maintenance engineers provide suppliers with market intelligence.
- Customers should keep suppliers informed of their technology plans while suppliers should align their technology plans with their customers' needs. Some instrument users/customers take a systematic approach to the analysis of future instrument needs.
- The development of new technologies by suppliers will depend upon the level of interest shown by customers for a particular instrument including the availability of funding.

- Suppliers vary in their approach to adopting new technologies. Some are more cautious than others, preferring to see evidence of customer take-up prior to committing development and production resources.
- The level of technology planning is very varied and often almost completely ad-hoc and informal. Some organisations have technology groups, involving representatives from different departments, which facilitate knowledge exchange. In some organisations a formal assessment of attractiveness/value of new technologies/instrumentation may be performed as part of a technology acquisition process.
- Technology planning should be a continuous process. Technology plans should address specific timescales, market trends, the potential for new markets and a consideration of alternative technologies (including step changes). They should include plans for technology insertion, avenues for research and development funding. Technology planning should be seen as a process which includes decision 'gates' to prevent nugatory expenditure. As a process it should be subject to process improvement within the organisation.
- Technology planning is constrained by the budgetary cycle and the customer internal bidding process for R&D funds. Technology sourcing involves a balance between retaining options and committing sufficient funds to a particular technology to gain some competitive advantage. This requires a high degree of technology awareness for which external assistance may be required.
- Technology planning needs to address enabling and competing technologies and address the specific capabilities of the organisation.
- Technology planning tools may not work perfectly and may not give the answers expected. For example, Roadmapping is a difficult concept that can become very complicated very quickly.

- One-off bespoke developments can cause a fragmentation of the technology plan. However, organisations working at the cutting edge of their field require bespoke instrument solutions since COTS items are unavailable.

There are only a few examples of technology push projects as they are much harder and tend to be collaborative. However, these projects seem to deliver revolutions rather than evolutions in instrumentation technology.

The end users of instruments do not usually select equipment by the number of extra “bells and whistles”. Their selection is made on what will best achieve their requirement to “get the job done”. Therefore, there is no evidence to support a misuse of instrumentation technology within this supply chain. Additional functionality is required for flexibility to “future proof” the purchased equipment. Any redundant options are usually the result of a change in the operational requirements rather than a lack of understanding of the functions.

Standardisation is patchy and is sometimes difficult to get suppliers to adhere to. Standards are difficult to produce due to equipment doing different things, and it is time consuming to write, agree & ratify. Some standards are not always helpful, others are unworkable. Standards are not always in the interest of suppliers due to the flexibility it provides the customer to switch between suppliers. The lack of standards makes the systems integrator’s task harder. In the case of this supply chain the systems integrator tends to be organisation 1.

In the context of organisation 1’s instrumentation supply chain the answer to Question 1:- “How is technology planning and management used in the R & D and Final User stages of the instrumentation supply chain?” can be summarised as follows.

Formal technology planning tools were not widely being used for the development of instrumentation throughout the supply chain. However, there were more informal approaches, for example, using experience and “gut-feel” and gathering information from customers and the scientific community. The reason for this is due to the instrumentation suppliers being very (almost too much) market driven. Suppliers waited until customers identified new needs and technology before carrying out developments. Suppliers may make incremental improvements to existing product ranges that tend to be evolutionary rather than

revolutionary. This leads to a very small amount of innovation coming from these suppliers. There was also a lack of awareness of what tools did exist and no structure that allowed technology planning to be incorporated as part of an already busy business process.

The tools that were used by the instrumentation customer community included discrete event simulation, brainstorming (committee of experts), roadmapping, technology monitoring (conferences journals etc.) and prototyping. The instrumentation supplier community that did use formal tools used brainstorming (committee of experts), focus groups, roadmapping, technology monitoring (conferences journals etc.), prototyping and experience and gut feel. Discrete event simulation is successfully used to explore process bottlenecks. Brainstorming provided mixed responses and depended on the quality and number of 'experts'. Roadmapping was found to get very complicated very quickly and required to be focused on a specific industry. It was usually used to focus on core rather than non-core technologies within the instrumentation customer community. Technology monitoring was found to be very time consuming and laborious to collect. In addition small suppliers found it difficult to identify which technology to back. Prototypes are used to gain buy-in to new concepts due to it being hard to justify step changes in technology with just a paper study. The author's own experience from the defence and aerospace sectors also supports this view.

It is believed by some organisations that instrumentation technology is mature and is not generally patentable. Hence, it can easily be outsourced and there is also no real need to invest in technological development. The author does not agree with this point of view. In fact it demonstrates that there is a real lack of technology awareness, planning and management. It appears that these organisations' technologies have been allowed to mature to the point that they are base technology, a prerequisite to compete in the market. If they had some form of technology planning and management it would have been bringing forward new technologies to replace the base technologies. They would have a portfolio of instrumentation technology spanning the spectrum of maturity from emerging to base. This misinterpretation of the situation can become an issue when trying to secure funding for research and development. However, this is not the view taken by Organisation 1, who see it as a way of delivering a competitive advantage.

In addition to the technology follower strategy by the suppliers, organisation 1 tended to drive technology advances in its instrumentation. Organisation 1's ability to develop instrumentation and to then pass on a detailed specification was, to a certain extent, stifling the innovation from its suppliers. Organisation 1, whilst it may use technology planning tools in its core activity of pharmaceutical development (untested by this study) it did not use these tools for the development of instrumentation.

Reviewing the propositions to question 1, the study found that all three were unsubstantiated for this particular instrumentation supply chain. The study provided the summary of statements related to proposition 1.1 shown in Table 6.

Ref	Research Question/ Proposition	Technology Issue Question	Study Response	
3	Q1, P1.1	What issues affect the way in which you perform your role – i.e. what stops them doing their job effectively?	Discussion answers see table 13.	
	Q1, P1.1	There is Technology Push	9 statements supporting the proposition (customer or supplier driven technology push)	25 statements not supporting the proposition (market driven developments)
5	Q1, P1.1	What are the issues associated with the capturing of end user requirements?	Discussion answers see earlier discussions and table 13.	
6	Q1, P1.1	Do you think briefings on latest technologies would be helpful?	The majority of interviewees used forms like conferences to receive updates on the latest technologies.	
47	Q1, P1.1	Do you receive detailed specifications of what is required?	20 statements relating to just waiting to receive a technical specification	18 statements relating to receiving capability requirements.
48	Q1, P1.1	Are these specifications normally what the user needs?	15 statements supporting the proposition	3 statements not supporting the proposition
50	Q1, P1.1	What are the issues associated with the capturing of end user requirements?	The majority of the statements identifying that the customers were experts not only in their science but also experts in instrumentation.	
51	Q1, P1.1	Is there a process for eliciting end user requirements?	There is usually a process for eliciting user requirements. The visibility of this process to the customer is not always clear.	
52	Q1, P1.1	How do you rate this process?	There was a range of answers from completely satisfied to some bad experiences.	
53	Q1, P1.1	How much is the development of technology driven by existing standards?	Generally there are not many technology developments that are being driven by standards.	
54	Q1, P1.1	Is this drive in the right direction?	Little comment obtained regarding this question given the answer above.	
55	Q1, P1.1	Do you think small instrument suppliers provide more innovative products than large suppliers?	There was a general feeling that the majority of the supply chain was waiting to be told what to develop and that most of the innovation was driven by the customer or by new entrants who have come up with an innovative idea. These small innovative companies tend to get taken over by large organisations looking to 'buy' their innovation.	
56	Q1, P1.1	What proportion of the equipment you purchase is for new types of measurement?	This question was biased towards the majority of instruments purchased being for new applications given that the study was exploring the R&D end of the value chain.	
	Q1, P1.1	Do you use a formal technology planning process?	Yes = 7 statements	No = 11 statements
	Q1, P1.1	If so what tools do you use?	Gut feel = 5 statements Discrete event simulation (1 statement) Brainstorming (committee of experts) (3 statements) Roadmapping (2 statements)	

Ref	Research Question/ Proposition	Technology Issue Question	Study Response	
			Technology monitoring (5 statements) Focus groups (2 statements)	
	Q1, P1.1	There is minimal user buy-in.	1 statement supporting the proposition	8 statements not supporting the proposition
10	Q1, P1.1	What information do you give the end user regarding the instrumentation needed to use your product?	Suppliers provide user manuals and telephone/on-line support.	
11	Q1, P1.1	What information do you give the end user regarding any training needed to use the instrumentation?	Suppliers provide training courses. However, these courses are not always required due to the skill levels of the end user	
12	Q1, P1.1	Is the end user involved with your technology planning process?	The majority of suppliers did not use a formal technology management process. Most of the suppliers worked on incremental developments that were customer driven.	
13	Q1, P1.1	Do you feel you are involved in the instrumentation suppliers' technology planning processes?	Although there was little formal technology planning within the instrumentation suppliers, 8 customer/end user interviewees stated that there was an open customer supplier relationship.	
	Q1, P1.1	There is minimal customer influence.	1 statement supporting the proposition	8 statements not supporting the proposition
24	Q1, P1.1	How do you affect decisions that are made – in particular with regard to the procurement of equipment?	The majority of end users and scientists make the decisions about what equipment is procured.	
25	Q1, P1.1	How do you make your decision?	These decisions are made mainly on the technical performance of the equipment rather than the cost	
26	Q1, P1.1	What trade offs do you need to make?	There is very little compromise on the technical performance of instrumentation, which takes precedence over everything else.	
27	Q1, P1.1	How often do you find the right piece of equipment for the right price?	Given the nature of the R&D work a large proportion of the equipment purchased is usually the result of some form of collaborative bespoke development.	
31	Q1, P1.1	What process does the organisation go through to plan for technology?	The use of formal technology planning processes within the supply was minimal. The processes that did exist were mainly related to incremental product development.	
38	Q1, P1.1	How market focused is the development of your products?	The supply chain is completely risk adverse and market driven. The result is that a large proportion of instrumentation innovation is generated by the customer/end user community.	
39	Q1, P1.1	How are customer feedback and market projections incorporated into product development strategy?		
40	Q1, P1.1	How do you monitor what your competitors are doing in terms of new product development?	Suppliers tend to use their relationships with their customer to gain knowledge about their competitors.	
85	Q1, P1.1	What is the procurement process for purchasing the instruments you use?	The process requires some form of technical justification and sign off. However, there is no requirement for a strong business case and to involve the procurement function of the organisation.	
91	Q1, P1.1	Are you aware of any suppliers that would assemble a system to meet your needs that would include integrating equipment from other suppliers?	Some suppliers would perform this role. However, the system would use all their own equipment rather than the selection of 'best of breed'	
92	Q1, P1.1	Do you find you need to assemble and integrate the system from multiple suppliers?	The customer tended to take this approach in order to use the 'best of breed' for each measurement technology.	
93	Q1, P1.1	How much do you spend on behalf of the company in supporting and maintaining this instrumentation (including calibration, training, supplier lock, liability and expectations)?	This figure was usually unknown as it came out of a different budget outside the control of the end user.	
100	Q1, P1.1	Who decides how this is specified?	It is not usually. Procurement decisions are made with little consideration for whole life costs.	
101	Q1, P1.1	How much influence do you have over the way in which such equipment is developed?	Users tend to have a large influence over how equipment is developed.	
103	Q1, P1.1	Do they believe this process is effective?	Mixed response from the customer community.	
104	Q1, P1.1	If not – what problems do they perceive exist?	Some comments relating to not assessing instrumentation effectiveness post delivery.	
106	Q1, P1.1	How much customer/end user input to this technology planning is there?	It is mainly a customer driven activity. Instrumentation innovation is a customer led activity.	
107	Q1, P1.1	Is this used to identify new technologies and to decide which ones the company should invest in?	The process is more focused around the core business of innovative science and looking for instrumentation technology that can provide solutions to support this science.	

Ref	Research Question/ Proposition	Technology Issue Question	Study Response
108	Q1, P1.1	Do you understand the technology involved in these non-core activities?	The customer community understands the technology involved in instrumentation to the point that they are expert users.

Table 6 Interview Statements Related to Proposition 1.1

Proposition 1.1: Customers/End Users and Final Users play a minimal part in the technology planning process within the R & D and Final User stages of the instrumentation supply chain - leading to technology push in the instrument supply chain with minimal user buy-in and influence.

Despite some contradictions in the statements from people within the same company and across the customer-supplier interface, the statements generally supported the following:

Conclusion 1.1: Customers/End Users and Final Users play a large part in the technology development process within the R & D and Final User stages of the instrumentation supply chain - leading to market pull in the instrument supply chain with strong user buy-in and influence.

The study provided the summary of statements related to proposition 1.2 shown in Table 7.

Ref	Research Question/ Proposition	Technology Issue	Study Response	
	Q1, P1.2	Instrumentation technology is misused. These statements came from the instrumentation suppliers and the author does not believe this is a true reflection of the situation. These statements are mainly driven by a misunderstanding of the customer's requirements by the supply chain.	14 statements supporting the proposition	0 statements not supporting the proposition
7	Q1, P1.2	What equipment do you require to perform your function within the organisation?	Various equipment types used. This was more a background question exploring what was being used etc.	
8	Q1, P1.2	Have you ever known any unneeded or unused functions to cause an instrument to fail? What were the consequences?	9 statements regarding extra functions causes reliability problems	6 statements regarding extra functions do not cause reliability problems
9	Q1, P1.2	Do you receive training on new instrumentation systems?	12 statements regarding receiving training	1 statement regarding not receiving training
58	Q1, P1.2	Are you aware of the full functionality of your instrumentation?	The majority of users are well aware of the functionality of the equipment they buy (at least 4 statements).	
61	Q1, P1.2	Are all the functions of their instruments fully utilised?	Not all functionality is used, however it is used to futureproof the equipment in a dynamic R&D environment.	
62	Q1, P1.2	How much training do you give your clients about the instruments you supply?	All suppliers interviewed provide training for their equipment.	
63	Q1, P1.2	Should more effort be made to make your customer/users aware of the full capability of the equipment supplied?	This was not really an issue within the supply chain studied.	

Table 7 Interview Statements Related to Proposition 1.2

Proposition 1.2: The full functionality of instruments is not being fully utilised leading to technology misuse within the instrumentation supply chain.

Conclusion 1.2: For organisation 1 the full functionality of instruments is being fully utilised. This does not support the idea that technology is being misused within this instrumentation supply chain. In fact, the end users of the instruments in this case are not only experts in their field of science, but also either expert or very experienced in the instrumentation required to support them.

The study provided the summary of statements related to proposition 1.3 shown in Table 8.

Ref	Research Question/ Proposition	Technology Issue	Study Response	
		Interfaces are compatible and there is a profusion of standards.	0 statements supporting the proposition	15 statements not supporting the proposition
22	Q1, P1.3	What instrumentation standards are you aware of?	Various standard types used. This was more a background question exploring what was being used etc.	
23	Q1, P1.3	Do you find these standards useful in your use of instruments?	Too few standards are available and those that are are open to interpretation.	
82	Q1, P1.3	In what way do these standards aid or hinder the integration of equipment?	3 statements aid integration	4 statements hinders integration
		There is incompatibility between bespoke systems.	0 statements supporting the proposition	15 statements not supporting the proposition
83	Q1, P1.3	Do you provide single items of equipment or do you provide an integration process?	Most suppliers will provide an integrated solution so long as it uses their equipment and/or some preferred associated instrument suppliers.	
84	Q1, P1.3	Do you provide or are you interested in providing an integrated solution?	Many would not be interested in providing integrated solutions that includes competing equipment.	

Table 8 Interview Statements Related to Proposition 1.3

Proposition 1.3: Instrumentation development is being driven by standardised interfaces and the profusion of standards making equipment compatible with bespoke systems.

Conclusion 1.3: Instrumentation development is not being driven by standardised interfaces and a profusion of standards making equipment compatible with bespoke systems.

In the context of organisation 1's instrumentation supply chain, the answer to Question 2:- "How effective are current technologies planning and management tools and processes within the instrumentation supply chain?" appears to be "not very" or "not at all". This is due to formal technology planning tools not being fully utilised in the supply chain.

The study did not totally support the proposition to question 2 for this particular instrumentation supply chain as follows. The study provided the summary of statements related to proposition 2.1 shown in Table 9.

Ref	Research Question/ Proposition	Technology Issue	Study Response	
	Q2, P2.1	There is a lifecycle mismatch between instrumentation requirements and equipment being available. These statements came from the customers and the author does not believe that the issues associated with lifecycle mismatch are totally due to the lack of technology planning. It is more to do with the lack of customer expectation management by the suppliers.	15 statements supporting the proposition in a mismatch of time. 22 statements supporting the proposition in a mismatch of performance.	1 statement not supporting the proposition in a mismatch of time. 3 statements not supporting the proposition in a mismatch of performance.
18	Q2, P2.1	Are new instruments generally available when you need them?	This is generally not an issue with COTS equipment. Lifecycle issues are generally associated with bespoke developments.	
19	Q2, P2.1	How do you plan for the delivery of the 'right' instrument when your process requires it?	General discussion used to establish existing processes.	
20	Q2, P2.1	How does the ease with which you can update instrumentation affect process improvement?	Extra functionality and ease of modification of instruments improves the futureproofing of equipment and helps in an R&D environment where requirements may change on a regular basis.	
21	Q2, P2.1	How easy do you find this ability to upgrade your instrumentation?	Varies from instrument to instrument.	
79	Q2, P2.1	What is your typical time to market for new products?	Varies from supplier to supplier and the complexity of the instrumentation system.	

Table 9 Interview Statements Related to Proposition 2.1

Proposition 2.1: Not many formal technology planning and management tools or processes exist or are used by the instrumentation supply chain leading to a lifecycle mismatch between instrumentation systems being required and instrumentation systems being available.

Conclusion 2.1: There are many formal technology planning and management tools or processes available. However, the instrumentation suppliers do not commonly use these tools, as innovation by the suppliers is fairly low. This does not directly lead to a lifecycle mismatch between instrumentation systems being required and instrumentation systems being available, since most of the innovation is carried out by the customer (organisation 1). Any lifecycle mismatch is due to a lack of expectation management, by both internal and external suppliers.

The study revealed that there is not always a strong link to a financial business case justification during the budgeting process for instrumentation. However, organisation 1 did use technology demonstrators to convince scientists and management of the benefits of new instrumentation.

The budgeting and procurement process seemed to be variable across organisation 1 depending on where in the organisation the equipment is being procured. During the procurement process, cost is usually a secondary issue to functionality and lifecycle costs are not generally considered during the purchasing decision.

There is also no review of actual equipment effectiveness to demonstrate the original business case. One example quoted, showed how automation had brought down the cost of producing a compound from £2500 to £50. There was no relationship to the cost of the equipment required for the automation and what was originally estimated the saving would be. Thus the effectiveness picture was incomplete.

Information to test the proposition that organisations spend a significant amount of their turnover on the procurement and maintenance of instrumentation was not obtained during the interviews. Therefore this proposition remains untested. Further information to link the significance of instrumentation to an organisation's bottom line was sought during phase 2 of the project and is beyond the scope of this PhD thesis.

From the study's observations it appears that large instrumentation suppliers tend to produce COTS equipment for a larger market that includes a number of potential customers. The interviewees indicated that the COTS market place was more profitable than producing one-off specials. Product developments in this scenario tend to be incremental and evolutionary. Smaller suppliers tend to deal in "specials" that involve a single customer. The small organisation breaks into the instrumentation market using a revolution that is the brainchild of an individual. This individual tends to have empathy with the end user of the equipment and understands the problems facing them and hence is able to spot a gap in the current market.

The development of "specials" saps a great deal of resources from a small company and with time, as they establish themselves, they try to break out of this responsive mode of operation into producing products for a wider market. At this point, or if they have a very novel product, it is not uncommon for the company to be sold to a larger organisation looking to augment their current portfolio of products.

The level of support provided by the supplier also appeared to have no consistent relationship to its size. In fact, the study indicated that geographical location played more of a role in responsiveness than size.

In the context of organisation 1's instrumentation supply chain, the study has not provided an answer to Question 3:- "What effect do instruments have on Customer/End User and Final User business performance with regard to their use in R & D facilities and in providing added value to the Final User?"

Further definition of the link between the use of instrumentation and the impact to the business was established during phase 2 of the project. It is also clear that this link does not exist within organisation 1 to establish the business case for instrumentation and to measure its effectiveness.

Hence the propositions to research question 3 were mainly inconclusive for this particular instrumentation supply chain.

The study provided the summary of statements related to proposition 3.1 shown in Table 10.

Ref	Research Question/ Proposition	Technology Issue	Study Response	
	Q3, P3.1	Impact on Bottom Line Generally this seemed uncharted territory within the customer community.	No statements indicating that payback of instrumentation was fulfilled.	2 statements indicating that payback of instrumentation was fulfilled.
28	Q3, P3.1	What are the major variables that affect the business' performance?	General discussion topic not fully explored in the study due to the commercial sensitivity of the information.	
95	Q3, P3.1	How is this measured?	There was no indication of any means of assessing instrumentation effectiveness.	
96	Q3, P3.1	What problems are you aware of with these variables and hence the business?	Not explored.	
	Q3, P3.1	Where Does Technology Bite?	Instrumentation technology in this supply chain is used to act as a force multiplier in the R&D process and is required to demonstrate and justify this role. Therefore having the right equipment at the right time not only constrains the ability to lever this force multiplier, it also can damage buy-in to its use.	
30	Q3, P3.1	What would happen if this instrumentation produced errors, failed or was unavailable?	There were a number of instances of this that led to a lack of end user buy-in.	

Table 10 Interview Statements Related to Proposition 3.1

Proposition 3.1: Instrumentation plays an important part of the Final User and End User/Customer's business process; hence instrumentation has a significant contribution to organisations' bottom line (e.g. profit).

Conclusion 3.1: There was no significant pattern to indicate whether or not instrumentation plays an important part of the Final User and End User/Customer's business process and hence instrumentation has a significant contribution to organisations' bottom line (e.g. profit).

The study provided the summary of statements related to proposition 3.2 shown in Table 11.

Ref	Research Question/ Proposition	Technology Issue	Study Response
	Q3, P3.2	Cost of Ownership	Mainly untested. However, it was established that whole life costs of instrumentation was not a major consideration during equipment selection or the procurement process.
14	Q3, P3.2	How important do you think this after sales care is for your customers?	Most suppliers believed this was very important.
15	Q3, P3.2	How do you rate the level of support you receive from your suppliers?	Most customers believed this was very important. It was also observed that this was a very important part of developing the customer supplier relationship. The customer worked very hard to help iron out problems so that next time the process would be smoother.
16	Q3, P3.2	How important to you is the ability to switch between suppliers? How easy do you find it?	There was little evidence of a switching culture within the customer community despite concerns over supplier lock. The majority of relationships were based upon working with people you have worked with before and can trust.
17	Q3, P3.2	Do you take into account the cost of: Calibration? Training? Reliability? (Down time of plant, cost of time to sort out problem, etc)	The main decision driver was technical performance.
71	Q3, P3.2	How does the range of after sales services between your suppliers compare?	There were no significant trends in this area, however there was a general view that small suppliers were less able to provide the level of support required due to resource constraints.
72	Q3, P3.2	What level of after sales care do you offer?	General discussions.
74	Q3, P3.2	How do you rate your needs for after sales support?	General discussions.
109	Q3, P3.2	How much does the company spend on supporting and maintaining this instrumentation (include calibration, training, supplier lock, liability and expectations)?	Not explored.
110	Q3, P3.2	How is such equipment procured – by your organisation or by your supplier?	This was explored in more detail as part of the rest of the project and modelled by Dr Michael Ernes
111	Q3, P3.2	How much does the company spend on the procurement of instrumentation?	No specific budgets discussed.

Table 11 Interview Statements Related to Proposition 3.2

Proposition 3.2: Organisations spend a significant amount of their turnover on the procurement and maintenance of instrumentation.

Conclusion 3.2: Untested - Organisations spend a significant amount of their turnover on the procurement and maintenance of instrumentation.

The study provided the summary of statements related to proposition 3.3 shown in Table 12.

Ref	Research Question/ Proposition	Technology Issue	Study Response	
	Q3, P3.3	Vendor Competition & Market Control The instrumentation supply chain is dominated by a few big supplier organisations that specify what instrumentation is available to industry, hence the vendor competition is low and market control by the suppliers is high.	There is no evidence to support this proposition. Instrumentation innovation was driven by the customer community. Given their size and spending power they exerted more influence and control over the supply chain than the other way round.	
2	Q3, P3.3	Do you think that small suppliers of instruments are more responsive than large suppliers?	More responsive = 6 statements	Less responsive = 3 statements
4	Q3, P3.3	Which instrumentation suppliers do you use and how would you categorise each one?	General discussion.	
		Large, institutional suppliers, good support, low responsivity	More responsive = 5 statements	Less responsive = 8 statements
		Large, fragmented suppliers, poor support, high responsivity		
		Small, dynamic suppliers, poor support, responsivity high->low		
41	Q3, P3.3	How market focused are your suppliers of instrumentation?	General discussion points.	
42	Q3, P3.3	What are the disadvantages of your products compared to your competitors?		
43	Q3, P3.3	What are the advantages of your products over your competitors?		
44	Q3, P3.3	How does the range of products compare between these suppliers?		
45	Q3, P3.3	For any given range of products, how many competitors do you have?		
46	Q3, P3.3	For any given type of instrument, what is the range of the number of suppliers?		

Table 12 Interview Statements Related to Proposition 3.3

Proposition 3.3: The instrumentation supply chain is dominated by a few big supplier organisations that specify what instrumentation is available to industry, hence the vendor competition is low and market control by the suppliers is high.

Conclusion 3.3: There was no correlation between the size of instrumentation supplier and their responsiveness to the customer to support this proposition.

3.1.4.1.3 Further Analysis of Interview Data

The data was analysed again by the author and his colleagues to extract the specific issues regarding technology planning and management from the interviews that would need

to be addressed by a technology planning and management lifecycle model. The following list (Table 13) of issues were identified and have been addressed and incorporated in the technology planning and management lifecycle model described in chapter 5. Each issue has a reference number that corresponds to a number highlighted by a circle on the model to indicate where in the model the issue is addressed.

No.	Implication On Model	Implication Category
1	Address maturity	Technology Planning
2	Technology plan addresses specific timescales	Technology Planning
3	Organisation does not do any formal technology planning	Organisation Specific
4	Technology planning tool needs to address technology insertion	Technology Planning
5	Organisation has a Strategic Technology Group	Organisation Specific
6	Can be a mismatch between development and requirement timescales	Lifecycle
7	Address step changes in technology	Technology Planning
8	Process affects product maturity	Business Environment
9	Conferences provide a forum for knowledge exchange	Technology Planning
10	Business case is reviewed by higher management	Business Environment
11	Address inter-dependence of technology plans of customers and suppliers	Technology Planning
12	Technology planning can be constrained by an internal bidding process	Technology Planning
13	Supplier technology developments rely on customer interest and/or funding streams	Technology Planning
14	Technology sourcing involves a compromise between keeping options open and backing a particular technology	Technology Planning
15	One-off specials cause fragmentation of technology development plan	Technology Planning
16	Cutting-edge technology requires bespoke solutions	Technology Planning
17	Technology push projects tend to be more difficult than market pull	Lifecycle
18	Technology plan addresses specific capabilities	Technology Planning
19	Technology can be missold	Value for Money
20	Intermediaries may spin off suppliers	Supply Chain
21	Technology demonstrators are used to prove concepts	Lifecycle
22	Technology demonstrators are used to gain end user buy-in	Lifecycle
23	Supplier needs to be aware of industry direction	Technology Planning
24	User's plans tend to be shorter term	Business Environment
25	No formal technology planning tools used	Technology Planning
26	Suppliers may perform formal assessment of attractiveness of technologies	Technology Planning
27	New ideas can come from competitors	Technology Planning
28	Organisation is technological leader	Organisation Specific
29	Suppliers may undertake technology planning	Technology Planning
30	Users sometimes undertake a systematic analysis of future instrumentation needs	Technology Planning
31	Address technology awareness	Technology Planning
32	Organisation has technology development process guidelines	Organisation Specific
33	Organisation uses brainstorming to plan for technology	Organisation Specific
34	Technology plan should include an opportunistic element	Technology Planning
35	Address enabling or competing technologies	Technology Planning
36	Professional bodies may provide a forum for knowledge exchange	Technology Planning

No.	Implication On Model	Implication Category
37	Technology planning tools may not give the answer expected	Technology Planning
38	Technology planning tools may not work perfectly	Technology Planning
39	Roadmapping is a difficult concept that can get very complex very fast	Technology Planning
40	Poor risk management is a barrier to innovation	Business Environment
41	Technology model needs to address the lifecycle issues	Lifecycle
42	Strategy should address research funding	Technology Planning
43	Technology planning groups may include departmental representatives	Technology Planning
44	Internal forum can facilitate knowledge exchange	Technology Planning
45	Technology planning is constrained by the budgetary cycle	Technology Planning
46	Technology planning can be continuous	Technology Planning
47	Include plans to develop new technologies	Technology Planning
48	Address technology planning	Technology Planning
49	Suppliers need to be aware of competing technologies	Technology Planning
50	Some suppliers are earlier adopters of technology than others	Technology Planning
51	Internal co-ordination of market intelligence within suppliers	Technology Planning
52	New technologies effects existing organisation	Technology Planning
53	Technology planning includes market trends	Technology Planning
54	New ideas can come from customers	Technology Planning
55	Technology demonstrators used to capture requirements	Requirements
56	Maintenance engineers provide market intelligence	Technology Planning
57	New ideas can come from support groups	Technology Planning
58	Technology may provide differentiation	Value for Money
59	Address new markets and new technologies	Technology Planning
60	Suppliers use bespoke procurements for technology development	Lifecycle
61	New ideas can come from users	Technology Planning
62	Standards can lead to technology push	Standards
63	Address choosing which technology to back	Technology Planning
64	Technology demonstrator may be configured from existing hardware	Lifecycle
65	Large companies can acquire new ideas by buying small companies	Business Environment
66	New ideas can come from suppliers	Technology Planning
67	Large companies do not always embrace new technology	Business Environment
68	Competition drives the time to market	Business Environment
69	Customer can be a source of competitor information	Technology Planning
70	New ideas can come from adapting existing products to new markets	Technology Planning

Table 13 Implications for The Technology Planning Model – Organisation 1

3.1.4.2 Organisation 2

For organisation 2, twenty-one one-hour interviews were conducted, at nineteen different organisations covering the landscape of precision farming shown in Figure 24. The interviewees ranged from farmers who were end users of the equipment, agronomists, original equipment manufacturers (OEMs) and application software developers.

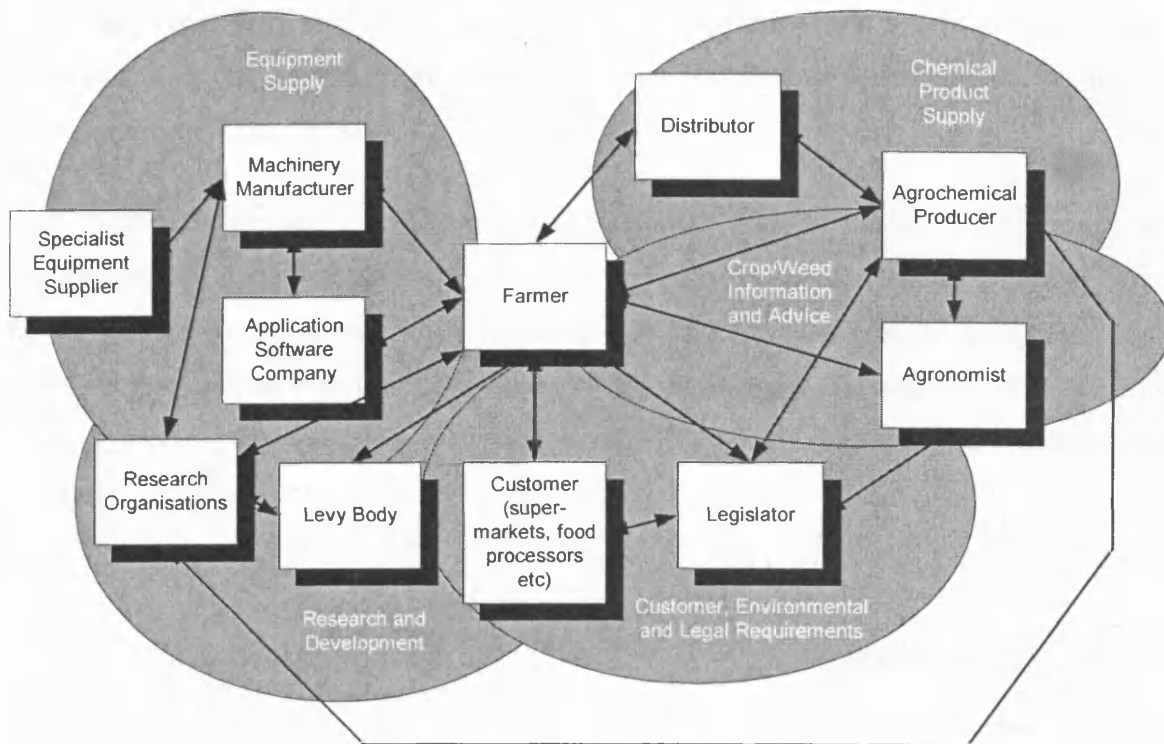


Figure 24 Landscape of Precision Farming

A total of 727 statements were loaded onto the database. Each of the research questions and associated propositions defined earlier were tested using a simple eyeball test (Campbell, 1975, cited by Yin, 1994, p25) against these interview statements. The purpose of the test was to see if an effects or no effects pattern existed to either accept or reject the propositions to the research questions.

The first iteration through the database reviewed the data and categorised each statement according to the list of key words given in Table 5, page 91. Five extra key words were added to this list to cover specific issues from organisation 2's supply chain. These extra key words are:

- End User Issues
- Development Approach
- Technology Misuse
- Lack Of Expectation Management
- Misselling Of Technology

Each statement could be associated with up to three key words as mentioned previously in section 3.1.4.1. Figure 25 shows the distribution of these statements categorised by their corresponding key words.

A second iteration through the statements challenged the original key word categories and re-categorised the statements into common groups of issues. The author aimed to look for the generic issue in the statement to reduce the influence of the specific situation. This second review also identified the implications for the Technology Planning and Management Lifecycle Model. A sample of the interview data and example of the reviews can be found in appendix 7.

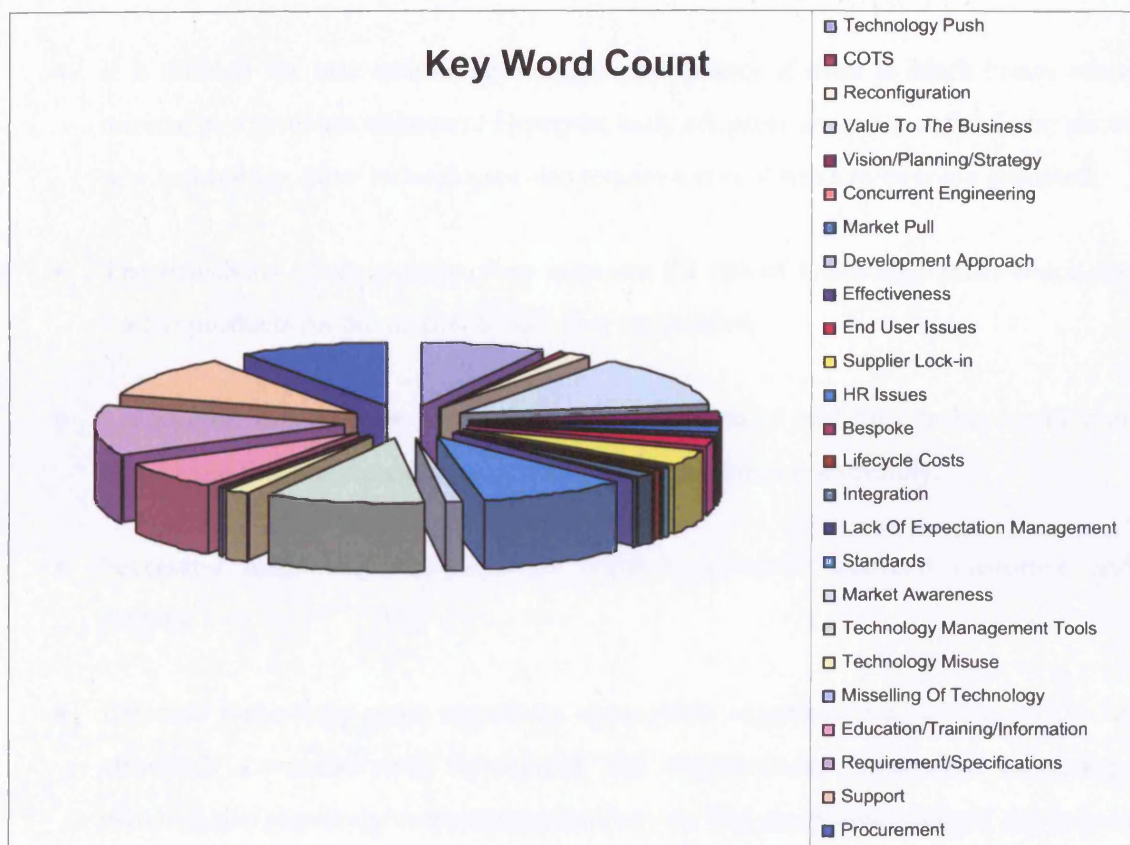


Figure 25 Distribution Of The Interview Statements By Their Corresponding Key Words

3.1.4.2.1 Sources of Bias

In addition to the sources of bias identified in section 3.1.4.1.1, this study only interviewed a sample cross section of the precision farming landscape shown in Figure 24

and that this sample were a group of 'like minded' organisations and individuals. Contacts for the study were obtained from the main organisations involved and hence the propagation of like minded individuals being used in the study. This was difficult to test for and remove from the data.

3.1.4.2.2 Testing of Research Questions and Propositions

The following observations were made from the interview statements regarding technology planning for the supply chain of organisation 2 (Smith et al, 2004):

- Keeping up to date with technology can be difficult if you are not a specialist or have matured your career sufficiently to be removed from the technology.
- It is difficult for new technologies to gain acceptance if used as black boxes when internal processes are unknown. However, early adopters are more enthusiastic about new technology. New technologies also require a critical mass to become accepted.
- The availability of cheap technology increases the risk of technology push which can lead to products on the market before they are needed.
- Technology may also be transferred between domains and new technologies may come from the commercial sector instead of the research community.
- Successful technology breakthrough requires openness between customer and supplier.
- Effective technology plans require an appropriate organisational culture and to be effectively communicated throughout the organisation. Successful technology planning also requires senior management buy-in. The interviewee believed this buy-in may be easier with engineers than senior managers as they understand the technical issues and the technology. However, the author believes this is not strictly true as senior management would take a more strategic view than engineers and therefore see its value
- Technology planning may be driven by a visionary.

- The technology plan should also address the requirements to compete in future scenarios and how the organisation should get to that position. Step changes in scenarios can cause radical changes in instrument requirements.
- The size of an organisation affects the technology planning decisions made.
- Technology planning requires input from the different organisation's functions. For example, feedback from sales reps can drive a particular technology development. Marketing people should communicate capability requirements to engineers rather than technology requirements. However, market research can over-estimate demand and would need to address when market and competitor assessment tools are used to drive technology plans.
- Technology planning should include space for free thinking. Some organisations may use brainstorming to create this free thinking.
- Product roadmaps are used for technology planning.
- Technology planning tools could include technology investment vs payback in future sales.
- Introducing new technology can have an impact on the whole supply chain.

As the GPS enabling technology became cheaply available from other industrial applications, there was initial technology push from the OEMs. However, with poor uptake of the technology and with no single organisation co-ordinating the integration of these technologies, the farmer has assumed the role of the systems integrator for precision farming and takes on the associated risk (Cowper et al, 2004).

The seasonal use of the equipment is a contributing factor to this and operators tend to ring up suppliers for help rather than read the manual. This does, to a certain extent, support the idea that technology is being misused within this instrumentation supply chain. Those farmers that are involved in the integration of such equipment, initially have domain knowledge, but may not have the technological knowledge of precision farming. However,

their skill level may be developing as they progress precision farming as essentially the farmer ends up being the systems integrator.

There is a lack of standardisation making the farmer's role as systems integrator very difficult. The main issue is compatibility of data formats as some OEMs try to use this as a form of supplier lock-in. Standards are not always in the interest of suppliers due to the flexibility it provides the customer to switch between suppliers. Some standardisation is being addressed for tractor and implements interfaces using the CANbus data bus standard. Again standards are difficult to produce due to equipment doing different things, and it is time consuming to write, agree & ratify.

In the context of organisation 2's instrumentation supply chain, the answer to Question 1:- "How is technology planning and management used in the R & D and Final user stages of the instrumentation supply chain?" can be summarised as follows.

Formal technology planning tools were not widely being used for the development of instrumentation throughout the supply chain. There were more informal approaches, for example, using experience and "gut-feel" and gathering information from customers and the farming community. Precision farming has been in the past very much pushed by technology. Suppliers tended to identify new technology and an application before carrying out developments. These applications did not always have a business case.

The tools that were used by the instrumentation customer community simply consisted of monitoring (conferences journals etc.). The instrumentation supplier community that did use formal tools used brainstorming (committee of experts), product routemaps (roadmapping), technology monitoring (conferences journals etc.), prototyping and experience and gut feel. Brainstorming was used on an ad hoc basis to provide breakthrough technologies. Routemapping was used by two supplier organisations. However, the maps were very focused on the customer (market place) and tended to show incremental developments. Technology monitoring was found to be very time consuming and laborious to collect. Prototypes are used to gain buy-in to new concepts due to it being hard to justify step changes in technology with just a paper study. The author's own experience from the defence and aerospace sectors also supports this view.

The technology push of precision farming has mainly occurred due to the availability of cheap GPS receivers enabling location based information to be gathered. This has been coupled with other technologies, for example satellite remote sensing using infra red and synthetic aperture radar (SAR), to deliver crop information services to the farmer. Initially there was a large amount of technology misselling. For example, GPS was used on combine harvesters to monitor crop yield. However, there was initially no real use for the data, so farmers ended up with this yield mapping data with no tangible benefits.

Reviewing the propositions to question 1 the study found that they were not supported by the interview statements. The study provided the summary of statements related to proposition 1.1 shown in Table 14. The statements generally supported the following conclusion.

Ref	Research Question/ Proposition	Technology Issue Question	Study Response	
3	Q1, P1.1	What issues affect the way in which you perform your role – i.e. what stops them doing their job effectively?	Discussion answers see table 21.	
	Q1, P1.1	There is Technology Push There were also 12 statements relating to technology being missold.	5 statements supporting the proposition	0 statements not supporting the proposition
5	Q1, P1.1	What are the issues associated with the capturing of end user requirements?	Discussion answers see earlier discussions and table 21.	
6	Q1, P1.1	Do you think briefings on latest technologies would be helpful?	The majority of interviewees used forms like conferences and the precision farming alliance to receive updates on the latest technologies.	
47	Q1, P1.1	Do you receive detailed specifications of what is required?	Equipment tends to be developed to meet a market need and tends to be COTS.	
48	Q1, P1.1	Are these specifications normally what the user needs?	The responses to the equipment in general is yes. However, in the specific case of precision farming the answer was no.	
50	Q1, P1.1	What are the issues associated with the capturing of end user requirements?	The main issue for precision farming was the lack of a clear business case (17 statements).	
51	Q1, P1.1	Is there a process for eliciting end user requirements?	There were various processes used to capture customer and user requirements.	
52	Q1, P1.1	How do you rate this process?	There was a range of answers from completely satisfied to some bad experiences.	
53	Q1, P1.1	How much is the development of technology driven by existing standards?	Generally there is not many technology developments that are being driven by standards.	
54	Q1, P1.1	Is this drive in the right direction?	Little comment obtained regarding this question given the answer above.	
55	Q1, P1.1	Do you think small instrument suppliers provide more innovative products than large suppliers?	There was no clear opinion on whether small suppliers had more or less innovation than large suppliers.	
56	Q1, P1.1	What proportion of the equipment you purchase is for new types of measurement?	The majority of equipment purchased was to replace equipment reaching the end of its useful life. New equipment for precision farming was only a small part of the overall spend and often came as part of the replacement equipment.	
	Q1, P1.1	Do you use a formal technology planning process?	Yes = 7 statements	No = 5 statements
	Q1, P1.1	If so what tools do you use?	Routemaps (2 statements) Technology monitoring (3 statements) Brainstorming (1 statement)	
	Q1, P1.1	There is minimal user buy-in.	The number of farmers using precision farming is currently only populated with the early adopters – those who have an interest in using the new technology. Precision farming has yet to make a	

			convincing case to bridge the chasm to reach the early majority.
10	Q1, P1.1	What information do you give the end user regarding the instrumentation needed to use your product?	Information is provided to the users, however, when there are problems it is easier for the farmers to pick up the phone and ask questions.
11	Q1, P1.1	What information do you give the end user regarding any training needed to use the instrumentation?	Training for equipment is provided by all suppliers. However, one of this issues is the seasonal use of the equipment and hence understanding of how the equipment operates fades with time.
12	Q1, P1.1	Is the end user involved with your technology planning process?	Most of the OEM had some form of process for understanding the future needs of their customers.
13	Q1, P1.1	Do you feel you are involved in the instrumentation suppliers' technology planning processes?	All the users felt they were not included in the early stages of any technology planning process. But they did get involved with the later stages of product development by testing equipment on their farms. Some of the farmers were also involved with various university and levy body research activities.
	Q1, P1.1	There is minimal customer influence.	6 statements supporting the proposition 5 statements not supporting the proposition
24	Q1, P1.1	How do you affect decisions that are made – in particular with regard to the procurement of equipment?	All purchases are made by the farmer and required a solid cost benefit case.
25	Q1, P1.1	How do you make your decision?	All farm equipment purchases are based on a strong business case and equipment purchases are significantly effected by the economic climate within farming (20 statements).
26	Q1, P1.1	What trade offs do you need to make?	All purchases are cost sensitive. However the second biggest selection criteria is the quality and locality of equipment support. If the dealer is just down the road and drops everything to fix a problem, the farmer will continue to purchase from them.
27	Q1, P1.1	How often do you find the right piece of equipment for the right price?	Various reponses.
31	Q1, P1.1	What process does the organisation go through to plan for technology?	The responses were variable. The farmers interviewed slightly biased the result as they were early adopters and tended to keep up to date with the latest developments in precision farming.
38	Q1, P1.1	How market focused is the development of your products?	Equipment suppliers are market driven = 7 statements
39	Q1, P1.1	How are customer feedback and market projections incorporated into product development strategy?	All equipment manufacturers use customer feedback using customer focus groups including non customers participation.
40	Q1, P1.1	How do you monitor what your competitors are doing in terms of new product development?	Competition monitoring is carried out through trade shows, agricultural shows etc.
85	Q1, P1.1	What is the procurement process for purchasing the instruments you use?	The approach varied and the selection criteria also varied.
91	Q1, P1.1	Are you aware of any suppliers that would assemble a system to meet your needs that would include integrating equipment from other suppliers?	There are no specific organisations that will take on the role of systems integrator. However some OEMs view providing a system as a way of ensuring supplier lock. That is, only their equipment can be integrated together without the need for additional software and/or hardware.
92	Q1, P1.1	Do you find you need to assemble and integrate the system from multiple suppliers?	All the farmers found that they had to perform the role of the systems integrator.
93	Q1, P1.1	How much do you spend on behalf of the company in supporting and maintaining this instrumentation (include calibration, training, supplier lock, liability and expectations)?	Answers varied.
100	Q1, P1.1	Who decides how this is specified?	The farmer/farm manager.
101	Q1, P1.1	How much influence do you have over the way in which such equipment is developed?	Suppliers tended to claim that customers had a great deal of influence over equipment development. However, individual farmers believed that they had little influence over equipment development.
103	Q1, P1.1	Do they believe this process is effective?	Equipment suppliers believe it was effective as it could be.
104	Q1, P1.1	If not – what problems do they perceive exist?	The main issue with precision farming is its definition of what a precision farming system is and does and the business case for it.
106	Q1, P1.1	How much customer/end user input to this technology planning is there?	There 6 statements indicating that technology is customer driven. However this contradicts the issue

			that there was a significant amount of technology push within precision farming.
107	Q1, P1.1	Is this used to identify new technologies and to decide which ones the company should invest in?	With the OEM precision farming technologies were seen as a way of "selling more metal".
108	Q1, P1.1	Do you understand the technology involved in these non-core activities?	The precision farming community understands the technology to a point – enough to cobble together a reasonable system. However, the end users are less technologically aware and some are not even computer literate. Hence they struggle as the equipment becomes more complex.

Table 14 Interview Statements Related to Proposition 1.1

Proposition 1.1: Customers/End Users and Final Users play a minimal part in the technology planning process within the R & D and Final User stages of the instrumentation supply chain - leading to technology push in the instrument supply chain with minimal user buy-in and influence.

Conclusion 1.1: Initially there was a great deal of technology push as GPS enabling technology became cheap and available to make Precision Farming viable. However due to the poor take-up customers/end users now play a relatively large part in the technology development process within the R & D and Final User stages of the instrumentation supply chain - leading to market pull in the instrument supply chain with strong user buy-in and influence.

The study provided the summary of statements related to proposition 1.2 shown in Table 15.

Ref	Research Question/ Proposition	Technology Issue	Study Response
	Q1, P1.2	Instrumentation technology is being misused.	Technology is being misused due to a certain amount of technology push (5 statements) the technology was initially missold (12 statements) and an unclear business case/use (17 statements). The technology also requires an increase in operator skill (8 statements), however, there is a lack of training available (4 statements). There is though an overwhelming view that there is a potential business case that just needs definition and proving (59 statements).
7	Q1, P1.2	What equipment do you require to perform your function within the organisation?	Precision farming technology enables a farmer to make decisions and treat crops in a resolution of less than one field. Therefore enabling the farmer to reduce in-field variability.
8	Q1, P1.2	Have you ever known any unneeded or unused functions to cause an instrument to fail? What were the consequences?	A mixed response to this question. Some additional functionality has lead inadvertently to a level of redundancy enabling the farmer to continue in the event of a partial failure. However, the additional complexity reduces the ability to "just get the job done".
9	Q1, P1.2	Do you receive training on new instrumentation systems?	Precision farming requires additional operator skill (8 statements) and training in precision farming is an issue (4 statements).
58	Q1, P1.2	Are you aware of the full functionality of your instrumentation?	Not all operators and farmers are fully aware of all the functionality of the equipment. Two interviewees stated that it was too complex and one said that the increased complexity reduces the ability to "just get the job done".
61	Q1, P1.2	Are all the functions of their instruments fully utilised?	Not all of the functions of the equipment are fully utilised. In some cases (e.g. yield mapping) the feature had no identifiable use. Hence yield maps were produced over several years with the farmers not knowing what to do with them.
62	Q1, P1.2	How much training do you give your clients about the instruments you supply?	All suppliers provide training. The quality of this training was not explored by this study. However, an issue that did arise is that the seasonal use of the equipment gave operators problems with the retention of knowledge regarding the equipment.
63	Q1, P1.2	Should more effort be made to make your customer/users aware of the full capability of the equipment supplied?	A more general point was that there is no precision farming teaching or training within agricultural colleges/agronomic courses. Therefore the next generation of agriculture workforce is not aware of the benefits/issues of precision farming.

Table 15 Interview Statements Related to Proposition 1.2

Proposition 1.2: The full functionality of instruments is not being fully utilised leading to technology misuse within the instrumentation supply chain.

Conclusion 1.2: The full functionality of instruments is not always being fully utilised which tends to support the proposition.

The study provided the summary of statements related to proposition 1.3 shown in Table 16.

Ref	Research Question/ Proposition	Technology Issue	Study Response	
		Interfaces are compatible and there is a profusion of standards. Lack of standards and compatible interfaces has been an issue. Any standards that were used were aimed at providing a lock into one supplier. However, the situation has improved standards are now being specified (3 statements) and used (6 statements). This was confirmed at the precision farming technology planning workshop discussed in chapter 7.	0 statements supporting the proposition	15 statements not supporting the proposition
22	Q1, P1.3	What instrumentation standards are you aware of?	These ranged from the CANbus standard (automotive databus) to data exchange formats, the latter being the less mature.	
23	Q1, P1.3	Do you find these standards useful in your use of instruments?	Those standards that did exist were useful for the farmers performing the systems integrator role.	
82	Q1, P1.3	In what way do these standards aid or hinder the integration of equipment?	Open standards, e.g. CANbus, aid integration and compatibility of data exchange. However, bespoke company standards prevented this and were used to provide supplier lock.	
		There is incompatibility between bespoke systems. Integration between different pieces of software is an issue.	4 statements supporting the proposition	0 statements not supporting the proposition
83	Q1, P1.3	Do you provide single items of equipment or do you provide an integration process?	OEMs can provide an integrated solution so long as it contains all their equipment. Some third party equipment and software suppliers provide integrating solutions. However, there are no complete systems integrators for precision farming – a role that is taken on by the farmer.	
84	Q1, P1.3	Do you provide or are you interested in providing an integrated solution?	Some third party suppliers are interested in providing integrated solutions or being systems integrators. However, until precision farming is more widely adopted, there is only a limited business case for them to develop into this role.	

Table 16 Interview Statements Related to Proposition 1.3

Proposition 1.3: Instrumentation development is being driven by standardised interfaces and the profusion of standards making equipment compatible with bespoke systems.

Conclusion 1.3: Instrumentation development is not being driven by standardised interfaces and a profusion of standards making equipment compatible with bespoke systems.

In the context of organisation 2's instrumentation supply chain the answer to Question 2:- "How effective are current technology planning and management tools and processes within the instrumentation supply chain?" appears to be "not very" or "not at all". This is due to formal technology planning tools only being used in limited areas of the supply chain which leads to technology push. A supply chain adoption of technology management tools is required in order to align technology availability and requirement.

The study did not support the proposition to question 2 for this particular instrumentation supply chain. The study provided the summary of statements related to proposition 2.1 shown in Table 17.

Ref	Research Question/ Proposition	Technology Issue	Study Response
	Q2, P2.1	There is a lifecycle mismatch between instrumentation requirements and equipment being available.	The lifecycle mismatch in this instrumentation supply chain has been caused by technology push bringing technology to a market not ready for it and the technology did not make a sound business case for its adoption. The technology push has also come up against the barrier of a mistrust of the technology (7 statements)
18	Q2, P2.1	Are new instruments generally available when you need them?	This is generally not an issue. The issue is being able to obtain a complete integrated system.
21	Q2, P2.1	How easy do you find this ability to upgrade your instrumentation?	Equipment is replaced on a cyclic basis. Each cycle takes advantage of the latest offering by suppliers.
79	Q2, P2.1	What is your typical time to market for new products?	Varies from supplier to supplier and the complexity of the instrumentation system.

Table 17 Interview Statements Related to Proposition 2.1

Proposition 2.1: Not many formal technology planning and management tools or processes exist or are used by the instrumentation supply chain leading to a lifecycle mismatch between instrumentation systems being required and instrumentation systems being available.

Conclusion 2.1: There are many formal technology planning and management tools or processes available which are generally used. However, this is mainly the equipment suppliers and there is a large amount of evidence that this led to a lot of technology push and misselling within the precision farming community. This leads to a lifecycle mismatch between instrumentation systems being available and the instrumentation systems being required. In many instances this means a technology may enable some form of measurement or activity to be conducted without a clear business case or reason why you need to do it.

The study revealed that there is not a strong link to a financial business case for the use of precision farming. This does not mean that there is not a potential business case, just that at the moment it is unproven. However, current precision farming activities are being carried out by a few 'believers' who are testing the viability of precision farming.

The budgeting and procurement process seemed to be variable across the industry and is dependent on the budgetary procurement cycles of farming. During the procurement process initial purchase and whole life cycle cost is usually a primary issue for equipment. For chemicals, the primary concern is the chemistry of the product and cost is a secondary consideration.

The economic climate of farming affects the procurement of equipment, especially precision farming equipment, as it has no clear business case. Farmers tend to use the price of grain as an economic indicator to the health of the industry.

Some agronomists see precision farming as a threat, either through increasing their work load or by changing or making their current role redundant. Other precision farming agronomists find some of the techniques of precision farming a useful tool.

Information to test the proposition organisations spend a significant amount of their turnover on the procurement and maintenance of instrumentation was not obtained during the interviews. Therefore this proposition remains untested. Further information to link the significance of instrumentation to an organisation's bottom line was sought during phase 2 of the project and is beyond the scope of this PhD thesis.

From the study's observations it appears that although equipment training is provided to farmers and operators, training in precision farming is an issue for both farmers and agronomists. Precision farming training is an issue as it involves new farming practices. Communicating new practices to the farming community is also an issue.

Some farm equipment is used only at a specific time of the year and if the equipment is complicated to use, it may prove an issue regarding operator's retention of knowledge. Operators tend to forget how to use equipment from one year to the next. Operators tend not to read the instruction manual, but instead call the equipment supplier's help line. This tends to overload this service at key points in the farming calendar, for example during harvesting.

The level of support provided by suppliers appeared to have no relationship to their size. In fact, the study indicated that geographical location of dealers played more of a role in

responsiveness than size. The location of dealership support is a selection criterion during the purchasing of equipment.

In the context of organisation 2's instrumentation supply chain the study has not provided an answer to Question 3:- "What effect do instruments have on Customer/End User and Final User business performance with regard to their use in precision farming and in providing added value to the Final User?"

Further definition of the link between the use of instrumentation and the impact to the business was established during phase 2 of the project and is linked to the technology planning models described later.

The propositions to question 3 were mainly inconclusive for this particular instrumentation supply chain. However the following observations were made. The study provided the summary of statements related to proposition 3.1 shown in Table 18.

Ref	Research Question/ Proposition	Technology Issue	Study Response
	Q3, P3.1	Impact on Bottom Line	Precision farming has no clear business case (17 statements), however, there is a potential business case (59 statements).
28	Q3, P3.1	What are the major variables that affect the business' performance?	Inputs: seeds, fertiliser (nitrogen, potassium, etc), pesticides (fungicides, insecticides, herbicides) Crop Yield Market rate for crop Weather
95	Q3, P3.1	How is this measured?	Farmers keep a very tight control over all these parameters with the exception of the weather which they monitor very closely.
96	Q3, P3.1	What problems are you aware of that cause problems with these variables and hence the business?	The ability to measure these parameters with a resolution of less than a field and hence understand and manage variability is the potential business benefit of precision farming. However, this is currently unproven.
	Q3, P3.1	Where Does Technology Bite?	The current level of technology in precision farming is ahead of the market need. The issue is how to bridge the gap between the early adopters and being able to obtain a complete integrated system.
29	Q3, P3.1	How important is the use of instrumentation in the way in which the product is used?	The ability to deploy a product (pesticide or fertiliser) variably in a field is essential for the success of precision farming and is technically feasible. However, the cost of this technology is very expensive.
30	Q3, P3.1	What would happen if this instrumentation produced errors, failed or was unavailable?	The failure of equipment would have an impact on the farmers ability to take advantage of critical time and weather windows during the growing season. For example cloud cover during satellite leaf area index mapping at the key nitrogen applications times is highly probable and restricts the ability to produce the maps to make application decisions. A more significant issue is if there was a real time system deploying products like pesticides, then a failure that caused crop contamination would be devastating for the farmer.

Table 18 Interview Statements Related to Proposition 3.1

Proposition 3.1: Instrumentation plays an important part of the Final User and End User/Customer's business process; hence instrumentation has a significant contribution to organisations' bottom line (e.g. profit).

Conclusion 3.1: There was no significant pattern to indicate that precision farming instrumentation plays an important part in the farmer's business process and hence instrumentation has a significant contribution to the farm's bottom line (e.g. profit).

The study provided the summary of statements related to proposition 3.2 shown in Table 19.

Ref	Research Question/ Proposition	Technology Issue	Study Response
	Q3, P3.2	Cost of Ownership	Mainly untested. However, it was established that whole life costs of instrumentation and a good strong business case was a major consideration during equipment selection or the procurement process.
14	Q3, P3.2	How important do you think this after sales care is for your customers?	Most suppliers believed this was very important.
15	Q3, P3.2	How do you rate the level of support you receive from your suppliers?	The farmers believed they got very good support from the dealership network and/or the suppliers themselves. This is not surprising as this was a very important selection criteria for the farmers. Any organisation that did not come up to scratch would be replaced.
16	Q3, P3.2	How important to you is the ability to switch between suppliers? How easy do you find it?	Farmers were very wary of supplier lock. To a certain extent farmers could easily switch suppliers. However, there was a very strong brand loyalty within the farming community.
17	Q3, P3.2	Do you take into account the cost of: Calibration? Training? Reliability? (Down time of plant, cost of time to sort out problem, etc.)	Farmers were very sensitive to whole life costs.
71	Q3, P3.2	How does the range of after sales services between your suppliers compare?	Difficult to judge however this is a very important selection criteria. Suppliers strive to provide the best service possible as it provides them with a differentiating feature.
72	Q3, P3.2	What level of after sales care do you offer?	Not fully explored.
74	Q3, P3.2	How do you rate your needs for after sales support?	Good local support is a selection criteria (8 statements)
109	Q3, P3.2	How much does the company spend on supporting and maintaining this instrumentation (include calibration, training, supplier lock, liability and expectations)?	Not explored.
110	Q3, P3.2	How is such equipment procured – by your organisation or by your supplier?	This was explored in more detail as part of the rest of the project and modelled by Dr Michael Emes
111	Q3, P3.2	How much does the company spent on the procurement of instrumentation?	No specific budgets discussed.

Table 19 Interview Statements Related to Proposition 3.2

Proposition 3.2: Organisations spend a significant amount of their turnover on the procurement and maintenance of instrumentation.

Conclusion 3.2: Untested - Organisations spend a significant amount of their turnover on the procurement and maintenance of equipment.

The study provided the summary of statements related to proposition 3.3 shown in Table 20.

Ref	Research Question/ Proposition	Technology Issue	Study Response
	Q3, P3.3	Vendor Competition & Market Control	Initially suppliers sought to gain lock-in through the use of bespoke standards and the lack of open standards which lead to some incompatibility issues. This situation has changed and has become more open and hence the issue is not as significant.
2	Q3, P3.3	Do you think that small suppliers of instruments are more responsive than large suppliers?	Not appropriate for the supply chain in question

Table 20 Interview Statements Related to Proposition 3.3

Proposition 3.3: The instrumentation supply chain is dominated by a few big supplier organisations that specify what instrumentation is available to industry, hence the vendor competition is low and market control by the suppliers is high.

Conclusion 3.3: There was not enough evidence collected to test proposition 3.3 and hence there was no correlation between the size of instrumentation supplier and their responsiveness to the customer to support the proposition.

3.1.4.2.3 Further Analysis of Interview Data

The data was analysed again by the author and his colleagues to extract the specific issues regarding technology planning and management from the interviews that would need to be addressed by a technology planning and management lifecycle model. The following list of issues (Table 21) were identified and have been addressed and incorporated in the technology planning and management lifecycle model described in chapter 5. Each issue has a reference number that corresponds to a number highlighted by a circle on the model to indicate where in the model the issue is addressed.

No.	Implication On Model	Implication Category
71	Keeping up to date with technology is difficult if you are not a specialist	Technology Planning
72	It is difficult for new technologies to gain acceptance if used as black boxes when internal processes are unknown	Technology Planning
73	Technology plan should address requirements to compete in future scenarios and how to get there	Technology Planning
74	New technologies require a critical mass to become accepted	Technology Planning
75	Technology plans should be effectively communicated to the organisation	Technology Planning
76	Marketing people should communicate capability requirements to engineers not technology requirements	Technology Planning
77	Size of business affects technology planning decisions	Technology Planning
78	Technology breakthrough requires openness with supplier	Technology Planning
79	Successful technology planning requires senior management buy-in	Technology Planning
80	Buy-in to technology planning may be easier with engineers as senior managers	Technology Planning
81	Technology planning should include space for free thinking	Technology Planning
82	Suppliers may use brainstorming to plan for technology	Technology Planning
83	Suppliers gain knowledge through trade journals	Technology Planning
84	Market research can over-estimate demand	Technology Planning
85	Technology tool could include technology investment vs payback in future sales	Technology Planning
86	Customers need the right products at the right time	Technology Planning
87	Technology may be transferred between domains.	Technology Planning
88	Technology push can lead to products on the market before they are needed	Technology Planning
89	Technology planning requires input from the different organisation's functions	Technology Planning
90	Early adopters are more enthusiastic about new technology	Technology Planning
91	Technology planning requires an appropriate culture	Technology Planning
92	Feedback from sales reps can drive technology development	Technology Planning
93	Step changes in scenarios can cause radical changes in instrument requirements	Technology Planning
94	Availability of cheap technology increases the risk of technology push	Technology Planning
95	Market and competitor assessment tools are used to drive the technology plan	Technology Planning
96	New technologies may come from the commercial sector instead of the research community	Technology Planning
97	Technology planning may be driven by a visionary	Technology Planning
98	Domain speciality clubs provide a forum for knowledge exchange	Technology Planning
99	Product roadmaps are a technology planning tool	Technology Planning
100	Introducing new technology can have an impact on the whole supply chain	Technology Planning
101	Small organisations may need to combine resources with other organisations to justify technology investment	Technology Planning

Table 21 Implications for The Technology Planning Model – Organisation 2

3.1.4.3 Comparison Between The Two Case Studies

The development of instrumentation within the supply chain of Organisation 1 tends to be mainly bespoke and technology development is very market driven. The development

of instrumentation within the supply chain of Organisation 2 tends to involve mainly COTS equipment and there has been a large amount of technology push. However, in both organisation's supply chains the systems integrator tends to be the end user/customer rather than the suppliers. The customer/user community of organisation 1 appears to be better placed to carry out the systems integrator role than that of organisation 2 due to the scientists being expert users of instrumentation.

For both supply chains the conclusion to research question 1 was the same; formal technology planning and management tools were not widely being used. This was due to a lack of awareness of the tools and a lack of business process framework to guide the organisations of when to use these tools. The customer community of organisation 1 had a large influence over instrumentation development. This is reflected in the fact that there was a lot more bespoke development and the suppliers were very market driven. For organisation 2, the customer community have very little influence over instrumentation development. This is a reflection of most of the equipment procured was off-the-shelf (COTS) and there had been a large amount of technology push within the supply chain.

For both supply chains the conclusion to research question 2 was that technology planning and management tools were not very effective. The main reason for this is their lack of use.

The conclusion to research question 3 for both supply chains was inconclusive.

Table 22 shows the comparison between the conclusions to the research propositions from organisation 1 and 2.

Organisation 1	Organisation 2
<p>Conclusion to proposition 1.1:</p> <p>Customers/End Users and Final Users play a large part in the technology development process within the R & D and Final User stages of the instrumentation supply chain - leading to market pull in the instrument supply chain with strong user buy-in and influence.</p>	<p>Conclusion to proposition 1.1:</p> <p>Initially there was a great deal of technology push as GPS enabling technology became cheap and available to make Precision Farming viable. However due to the poor take-up customers/end users now play a relatively large part in the technology development process within the R & D and Final User stages of the instrumentation supply chain - leading to market pull in the instrument supply chain with strong user buy-in and influence.</p>
<p>Conclusion to proposition 1.2:</p>	<p>Conclusion to proposition 1.2:</p>

Organisation 1	Organisation 2
For organisation 1 the full functionality of instruments is being fully utilised. This does not support the idea that technology is being misused within this instrumentation supply chain. In fact, the end users of the instruments in this case are not only experts in their field of science, but also either expert or very experienced in the instrumentation required to support them.	The full functionality of instruments is not always being fully utilised which tends to support the proposition that technology is being misused within this instrumentation supply chain.
Conclusion to proposition 1.3: Instrumentation development is not being driven by standardised interfaces and a profusion of standards making equipment compatible with bespoke systems.	Conclusion to proposition 1.3: Instrumentation development is not being driven by standardised interfaces and a profusion of standards making equipment compatible with bespoke systems.
Conclusion to proposition 2.1: There are many formal technology planning and management tools or processes available. However, the instrumentation suppliers do not commonly use these tools, as innovation by the suppliers is fairly low. This does not directly lead to a lifecycle mismatch between instrumentation systems being required and instrumentation systems being available, since most of the innovation is carried out by the customer (organisation 1). Any lifecycle mismatch is due to a lack of expectation management, by both internal and external suppliers.	Conclusion to proposition 2.1: There are many formal technology planning and management tools or processes available which are generally used. However, this is mainly the equipment suppliers and there is a large amount of evidence that these has led to a lot of technology push and misselling within the precision farming community. This leads to a lifecycle mismatch between instrumentation systems being available and the instrumentation systems being required. In many instances this means a technology may enable some form of measurement or activity to be conducted without a clear business case or reason why you need to do it.
Conclusion to proposition 3.1: There was no significant pattern to indicate whether or not instrumentation plays an important part of the Final User and End User/Customer's business process and hence instrumentation has a significant contribution to organisations' bottom line (e.g. profit).	Conclusion to proposition 3.1: There was no significant pattern to indicate that precision farming instrumentation plays an important part in the farmer's business process and hence instrumentation has a significant contribution to the farm's bottom line (e.g. profit).
Conclusion to proposition 3.2: Untested - Organisations spend a significant amount of their turnover on the procurement and maintenance of instrumentation.	Conclusion to proposition 3.2: Untested - Organisations spend a significant amount of their turnover on the procurement and maintenance of equipment.
Conclusion to proposition 3.3: There was no correlation between the size of instrumentation supplier and their responsiveness to the customer to support this proposition.	Conclusion to proposition 3.3: There was not enough evidence collected to test proposition 3.3 and hence there was no correlation between the size of instrumentation supplier and their responsiveness to the customer to support the proposition.

Table 22 Comparison Of The Conclusions To The Propositions For Organisations 1 And 2

3.2 Summary

The study detailed in this chapter was based upon research literature, best practice and a series of issues from the participating organisation's experiences and outputs from the DTI Intersect Faraday Partnership meetings (the Intersect Faraday Partnership is managed by Sira and NPL). The main finding from the study is that formal technology planning and management tools are not being used within the instrumentation supply chains. This leads to ineffective technology planning and management within these supply chains which in turn has given rise to missold technology in one supply chain and a lack of innovation in the other. The reason for the lack of use of such tools is due to a lack of awareness of the tools and a lack of supporting business process framework in which to use them. A list of technology planning and management issues has been identified.

This thesis will now explore the development of a technology planning and management lifecycle model that will address the main finding from the study. Each of the technology planning and management issues identified has been addressed and incorporated in the technology planning and management lifecycle model described in chapter 5.

Chapter 4

4. MODELS OF THE EXISTING TECHNOLOGY PLANNING TOOLS

The tools reviewed in chapter 2 have been modelled using the Unified Modelling Language version 1.x (UML) (Rumbaugh et al, 1999) (Holt, 2001). The models were generated using the UML extension to Microsoft VisioTM and the extensions proposed for business process modelling by Eriksson and Penker (2000, pp419-427). Not all of Eriksson and Penker's formats could be adopted due to the constraints of Microsoft VisioTM.

Modelling these tools enabled the author to gain a deeper understanding and to see how they fit together in the context of an overall technology planning process. The modelling exercise also identified the limitations of each tool and where there are gaps within the overall process. The following sub-section details the modelling approach and appendix 8 provides an example of this exercise using Metz Best Practices. A complete set of models has not been included as large parts of these models are used in the lifecycle model described in chapter 5 and to avoid repeating the descriptions given previously in chapter 2.

The models were peer reviewed to check for consistent use of the UML syntax, the commonality between models, where they are useful and how they fit into the bigger picture. One challenge identified by the peer review was the modelling of processes. A process could be modelled as either a 'class' or as an 'activity' which led to some inconsistencies between the various diagrams of the models. This was overcome by defining that a process is an activity and not a class. This classification dilemma is similar to one discussed by Cowper & Smith (2002, pp261-268) when exploring the situation where a project that creates systems is also a system itself.

The modelling peer review identified a number of points in addition to the advantages and disadvantages explored in chapter 2 and listed in appendix 1. These review points are raised as each model is discussed in this chapter and have a reference number in brackets (RP*number*). These issues are then addressed in the Technology Planning and Management Lifecycle Model described in chapter 5 and referenced.

4.1 Modelling Approach

UML is an object-oriented language that was originally developed for software engineering, but is now widely used for systems engineering and business process modelling. UML was found to be very convenient for documenting the key objects and processes involved in technology planning and management. The author found that the UML class, state chart and activity diagrams could together adequately and completely describe any of the technology planning and management processes examined. The class diagram was used to define the static relationships between objects, the state chart diagram was used to show how the states of objects changed as they moved through the process, and the activity diagram was used to describe how different parts of the process required different input objects and generated different output objects. The use of activity diagrams largely adopts the conventions of Eriksson and Penker's (2000, pp419-427) approach to business process modelling.

The approach adopted was to consider the relationships between the objects participating in the processes (using class diagrams) and the flow between the processes (using activity diagrams) iteratively (Emes, Cowper & Smith, 2005), see Figure 26. Thinking about the objects in the system can reveal new ideas about processes, and thinking about the processes can highlight objects involved in the process that had not previously been identified. Similarly, class diagrams helped to identify when it was preferable to think of an object as one class that changed state as opposed to two or more distinct classes. Activity diagrams also highlighted the input and output objects from a process and this often generated ideas about object states. Hence, state chart diagrams also evolved iteratively as the model developed.

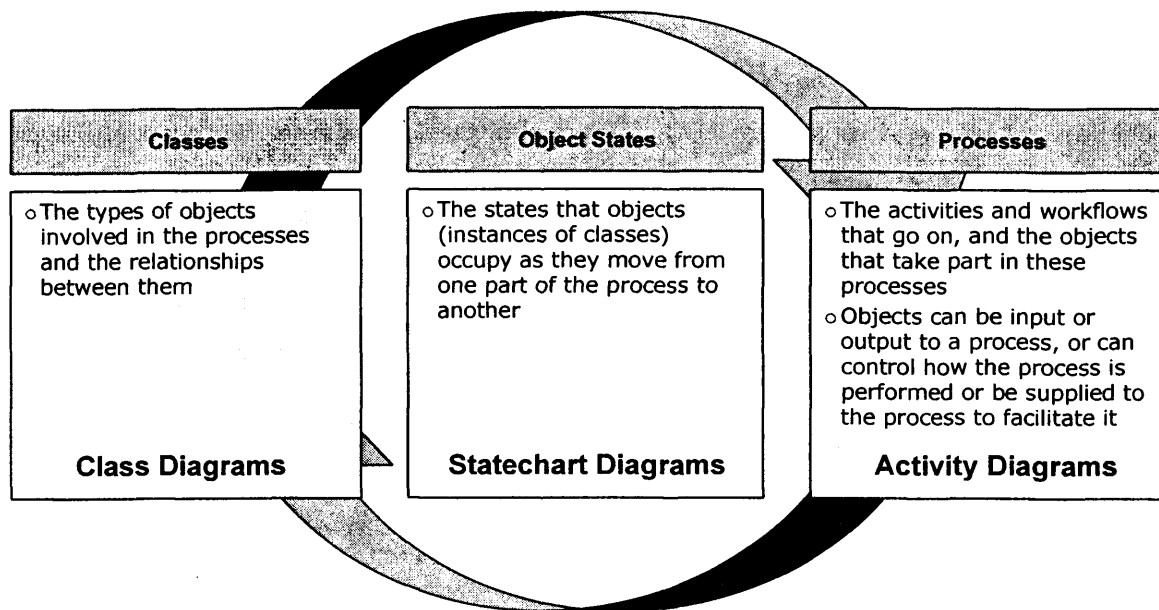


Figure 26 UML Modelling Approach (Emes, Cowper & Smith, 2005)

4.2 Peer Review Of Existing Technology Planning Tool Models

This section provides the observations from the peer review of the existing technology planning tool models.

4.2.1 Attribute Analysis & Quality Function Deployment

The review of this model derived similar conclusions to the Schema and Morphological Analysis and Relevance Tree reviews discussed later.

4.2.2 Needs Research

Needs Research is linked to Attribute Analysis, in that Attribute Analysis focuses in on the product and Needs Research focuses in on the customer. Customer needs analysis addresses how customers needs evolve over time. (RP1)

The parts of the model used to focus on the customer are a useful complement to attribute analysis. The aspects associated with the investment decision are only useful if needs analysis is being conducted in isolation. (RP2)

4.2.3 Relevance Tree

This method is another way of breaking down morphological features and can therefore be coupled with the Morphological Analysis to explore how the features link together. (RP3)

One would expect to find that there are a series of Technology S Curves at the different levels. (RP4) The interesting point about the Technology S Curves in this type of structural analysis is which one really applies, ie at system or component level? (RP5)

This method also fits with our Architectural Novelty Model (Cowper et al, 2005) and can help to identify where the novelty (risk) is high and can allow one to focus on the high risk items. (RP6)

4.2.4 Schema & Morphological Analysis

The review of the Schema & Morphological model identified that it overlaps with TRIZ in that it breaks down a system into its constituent features (RP7). The useful parts of the model are the bottom two boxes of the class diagram i.e. the feature of the technical structure and the logical feature solution. This part of the model needs to capture “What are you trying to achieve?” and “Why are you trying to achieve it?” (RP8). These questions also need to link to the value side of the wider model, that is, the bottom line in order to be able to select the best options.

The level of technology within the system structure also plays a part here (RP9). For example, at the system level influences like market forces and people play an influencing part in the natural limit – eg what is the acceptable weight of a laptop computer? At a component level physics plays a more important part. These factors relate to the architectural novelty factor discussed by Cowper et al (2005).

4.2.5 Committees Of Experts & Delphi

Due to the similarity of the Committees of Experts and the Delphi techniques, it was decided to only model the Delphi technique. The review of the Delphi model raised the following questions regarding the technique: (RP10)

- How does this work in practice?
- Do the experts get fed up with being asked to check and change their answers?

- How big is the panel?
- Who selects the experts and from what background?

There is still a possibility of getting a conflict of ideas between the various backgrounds of the experts. (RP11)

The answers to the questions in terms of technology are only as good as the questions in the questionnaire. (RP12)

This method requires a lot of effort and may therefore be restricted to a large organisation with the adequate resources. (RP13)

There needs to be some form of check for market size. (RP14)

At some level in the model a check needs to be made about whether the organisation conducting the technology planning process has access to people who can make these predictions. Do you have the knowledge or skills to do this? Who can you turn to for help? If you get stuck can you identify who can help? Is there anyone who can help you find the right people? (RP15)

Are cost benefit trade offs being carried out at a specific point in the process or is it something that runs in the background of the whole process. (RP16) Note for model: what information is required, what help is needed, what are the inputs and outputs, what are the cost benefits? (RP17)

4.2.6 Complexity Theory

As previously discussed, there are no current models of the use of complexity theory in technology planning. Any technology planning complexity model would need to be developed and therefore there is no UML model for this potential tool. It was also decided that the investigation of the use of Complexity Theory for technology planning was beyond the scope of this project. However, it would make an interesting topic for further work in this field.

4.2.7 Discrete Event Simulation

Discrete Event Simulation is used to model and simulate processes to visualise flow through the process, optimise process throughput and identify bottlenecks. The use of Discrete Event Simulation involves modelling one's process in a simulation software tool and therefore it was decided that there was no value in modelling Discrete Event Simulation in UML for this project.

4.2.8 Focus Groups & Technology Footprinting

The technology categories link to the rate of change of the S curve. (RP18)

The competitive impact links to Morphological Analysis – why we need the technology and what happens if I don't get involved in researching this? (RP19)

Which ones are important? A lot is outside your control. (RP20)

Note for the model: most of these models seem to be defining systems rather than evaluating the technology within them. (RP21)

4.2.9 Game Theory

The review of the Game Theory model suggested that this could be used in conjunction with Scenarios to provide “what if?” situations that senior management could base decisions on. (RP22)

4.2.10 Nominal Group Technique

Solution ranked top may be influenced by the personalities involved. (RP23)

It does not involve a questionnaire and has more input from the experts and can be concluded in a single day. (RP24)

This method seems useful when ideas are less well formed and not quantitative. It is similar to brainstorming and could be combined with Delphi as a follow up. (RP25)

This method requires some form of follow up on solutions to challenge and explore the implications of the solutions. (RP26)

4.2.11 Scenarios

Scenarios underpin decisions. The scenarios have to be present in the mind of the decision maker. (RP27)

Scenarios are based on the theory that no one scenario is no more probable than another, ie they are all of equal weight. The weakness of scenarios is that it does not use probability to weight the scenarios so that one keeps all the options open and caters for all eventualities. This is practically impossible to do as organisations will have a finite amount of resource and will be looking to identify what is likely to give you the “biggest bang for the buck”. (RP28)

Scenarios and game theory are very important in evaluating the cost benefit side of the R&D investment decision. (RP29)

4.2.12 Trend Model – S Curve

The review of the Trend model identified that it could be very misleading to try to predict where you are on the curve. (RP30) The only useful things about this model are the natural limit and the current rate of change of technology. (RP31) It could be useful as a reflection tool enabling you to look at what has happened historically, but it will not help you understand how it is going to get to the natural limit. (RP32) There are too many influential factors – most of which are beyond your control. (RP33) To try and predict these influential factors is very complex and is where, perhaps, complexity theory may help. The initial conditions have a big impact on the outcome and therefore could be linked to this model. One may be able to influence the start conditions of the process although the process is beyond your control.

4.2.13 TRIZ

The technical system and system of systems concepts are similar to those used in Attribute Analysis. The maturity model is similar to the S Curve. These points will be addressed in the new model. (RP34)

Technology conflict constraining technology is useful in the Roadmapping technique. (RP35)

The contradiction matrix and the TRIZ principles (these are only a snap shot in time and do not reflect current technology developments) are not useful and should not be included in any detail in the model. (RP36)

TRIZ is similar to Needs Research in that it analyses the needs of the customer and identifies needs not met by existing technologies. Therefore any potential gap for a particular type of product provides an input to the TRIZ process. (RP37)

4.2.14 Audit

It seems that an audit just tells one how good one is at developing the technologies audited. (RP38)

4.2.15 Benchmarking

Benchmarking links into Technology Footprinting. (RP39)

Benchmarking needs to link to core competencies, value and control. (RP40)

Benchmarking requires one to define measures in order to obtain a 'before and after' picture. (RP41)

One of the pieces in one's quantitative jigsaw is to demonstrate one's performance in comparison to best practice and the competition. Again Benchmarking requires a definition of what is being compared. (RP42)

To help make better decisions one needs to ask the questions (RP43):

1. How good is the technology?
2. How good am I at developing the technology?

4.2.16 Technology Monitoring

The peer review of this model had no specific points to raise, accept that this needs to be included in the Technology Planning and Management Model as a mechanism for technology awareness. (RP44)

4.2.17 Technology Readiness Levels

The peer review of the Technology Readiness Levels model highlighted that these levels seem to have limited value in terms of classification of technology maturity. They help the mapping of technology (technology insertion) on to the product design process. However, the review was not sure about the mapping on to the S Curve. (RP45)

4.2.18 Metz Five Best Practices Of Technology Planning/Business Planning

The review of the Metz model raised the following questions:

1. Is Metz saying these best practices are the characteristics needed for successful technology projects? (RP46)
2. Management commitment and organisational buy-in; what are the things that can achieve and maintain this? (RP47)
3. To what extent do the five practices fit into the model? (RP48)
4. Can the model be achieved if these five best practices are not present? (RP49)

Regarding question 1, Metz's research involved surveying 40+ leading companies in high technology industries and identifying common traits that made them successful. There may be cases where projects are successful without all five best practices; however, it improves your chances of success if all five practices are present. The author aims to address all five practices in the technology model.

Regarding question 2, from the study in chapter 3, it is very important that there is management commitment and organisational buy-in for technology projects to be successful. Again the author aims to address this in the model, by making the technology drivers fit with the business and marketing objectives of the organisation. This provides senior management with a traceable link back to the bottom line for investing in technology development. By getting the organisation involved in the more detailed parts of the technology planning process, it should ensure some form of ownership of the technology plan and hence buy-in to its delivery.

In answer to points 3 and 4 the model will try to incorporate all five practices. The extent to which all five practices are implemented will be down to an organisation's interpretation and application of the model. However, the model should empower an organisation to do their own technology planning and not to rely on another organisation to do it for them. They should also have some form of process review in order to improve and optimise the technology planning process for their commercial environment.

4.2.19 Roadmapping

The S Curve and Footprinting provide the lifespan of a technology. However, different technologies within a product will have different life spans and will therefore come and go. (RP50)

Roadmapping is useful for identifying the different technologies that come on stream. However, its weakness is that the ability to predict into the future is difficult. It requires some form of group technique to make the predictions and you will need different roadmaps for different scenarios. (RP51)

Roadmapping has some similarities with Attribute Analysis. (RP52)

Roadmapping's main benefit is that it provides a graphical summary for management. (RP53)

4.3 Summary

The technology planning and management tools reviewed in chapter 2 have been modelled using the Unified Modelling Language version 1.x (UML). Modelling the tools enabled the author to gain a deeper understanding and to see how they fit together in the context of an overall technology planning process. The modelling exercise also identified the limitations of each tool and where there are gaps within the overall process. The modelling peer review identified a number of points in addition to the advantages and disadvantages explored in chapter 2 and listed in appendix 1. These review points are raised as each model is discussed in this chapter and have a reference number in brackets (RP $number$). These issues are then addressed in the Technology Planning and Management Lifecycle Model described in the next chapter (5) and referenced.

Chapter 5

5. DEVELOPMENT OF A TECHNOLOGY PLANNING AND MANAGEMENT LIFECYCLE MODEL

This chapter uses the review of existing technology planning and management tools covered in chapter 2, the results of the study into the current situation within the pharmaceutical and agrochemical industries' supply chain covered in chapter 3 and the UML modelling of the existing technology planning and management tools covered in chapter 4. The development of the technology planning and management model addresses the issues identified by the study and also aims to plug the gaps that exist in the tools available.

5.1 How Do The Technology Tools And Processes Fit Together?

As an Engineering Manager in a company developing instrumentation for the aerospace industry, the author was responsible not only for the engineering required to develop new products, but also for the engineering input to the company's 5-year strategy plan and the implementation and delivery of that plan. This included determining what technologies the company needed to invest in to deliver the product set identified by marketing and what skills were required by the engineers in the team.

The basic process was as follows:

- Identify customers' future needs in terms of programmes, platforms and products.
- What product portfolio do we need and what exists already?
- What technologies are these products likely to deploy?
- What skills are required by the engineers and production staff to design, develop and make these products?
- Do we buy these technology skills in or do we develop them internally?

There are a number of limitations with this process and the author had difficulties in securing the time and resources required to implement the strategy. This was partly due to a lack of awareness of the tools available (see the review of planning tools in the preceding

section), partly due to an unclear business case for the development, and partly due to not enough time being allocated to the implementation of the strategy.

This failure is summarised by Floyd (1997, p183) "We need to be more innovative. We know we've done all the right things with strategy and structure, but somehow we are failing to make it happen".

There is a wide range of texts that identify a process for the planning and implementation of technology and essentially are a variation on a theme. Some of these also advocate a "systems approach" to the subject (for example, Cardullo, 1996, p29 and Schulz, Clausing, Fricke & Negele, 2000, pp185-186). The aim of the following sub-sections is to "walk through" a generic technology planning and management process.

5.1.1 Technology Planning

The key elements that the technology plan should include are:

- Meet the objectives of the business and identify future customer needs (Technology Planning Inputs).
- Identify the technology required to deliver those needs (Technology Planning Inputs).
- Predict future technology performance growth (Technology Forecasting).
- Establish what the current technology base of the company is and how this compares to the strategy (Internal Technology Review).
- Compare the company's technology with the competitors' and establish what the competitors are doing (External Technology Review).
- Decide which technologies to take forward (Technology Planning).
- Decide how the company obtains its technology – in other words "make-or-buy" (Technology Acquisition).
- Identify the sources of this technology (Technology Acquisition).
- Define how this technology is integrated into the business through product, processes and services (Technology Implementation).
- Decide which existing technologies to keep investing in (the author suggests the term Technology Maintenance).

- Decide which existing technologies need to be disposed of and how this will take place in conjunction with the introduction of replacement technologies (the author suggests the term Technology Replacement).

For example Floyd (1997, p33) depicts the process as being iterative, as shown in Figure 27.

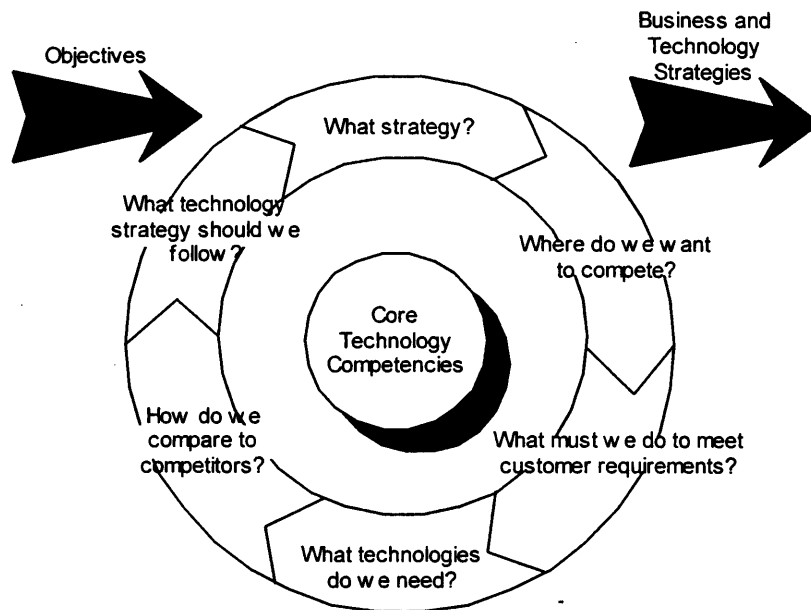


Figure 27 Structured Approach To Business And Technology Strategy (Arthur D. Little Ltd cited by Floyd, 1997, p33)

The development of a technology plan will identify where the company currently is, where it would like to go and what it will need to do to get there. The formulation of the plan will aim to develop a balanced portfolio of technologies (for example, some high risk, potentially high gain and some low risk, potentially low gain) and will determine whether the company wishes to consider itself as a leader or follower in each technology (Metz, 1996, pp118-120).

Part of the decision making process will rely on analysing the risks and rewards using economic and technology forecasting models, for example Discounted Cash Flows and portfolio management.

5.1.2 Technology Planning Inputs

Figure 27 indicates that the technology process is cyclic and may involve a number of iterations. Each stage will require a number of inputs which will be generated during that stage, see following sub-sections, starting with the marketing and business strategy objectives.

The development of the marketing strategy will identify the commercial environment in which the organisation operates and utilises a number of tools to perform the analysis, for example SWOT (strengths, weaknesses, opportunities and threats), Porter's five forces model, etc.

It is important that this plan is linked to the technology plan in order to identify what sort of products and services the customers in the organisation's industrial sector require. This will form the basis for identifying what technologies are required to support these products and services. In addition, the technology management process needs to feed back into the marketing plan what technology developments potentially threaten existing products through obsolescence and substitution and what industry inertia threatens the introduction of new technology. An example of this is in the certification of safety critical systems. This can be a problem when a certification body is nervous about introducing unproven technology into applications where failure will cost human life. It was only in the mid 1990's, for instance, that the civil aviation authorities considered it to be acceptable for standby instruments in aircraft to use solid-state (semiconductor) technology as opposed to the traditional electro-mechanical technology.

The business objectives and marketing strategy will indicate the direction and shape of the business in the future and the development of technology also needs to address this requirement.

There are a number of methods used for eliciting requirements and understanding customers' needs (Macaulay, 1996, p9), such as Checkland's (1981) Soft Systems Methodology (SSM). Some of these have been covered in the previous section, for example, needs research, attribute analysis and Quality Functional Deployment (QFD) (Cohen, 1995).

5.1.3 Technology Forecasting

Betz (1998, pp159-163) defines technology forecasting as NOT being simply a vision, science fiction or otherwise, but is technological change that is scientifically feasible and is

about the rate and direction in which technological progress can occur. Betz (1998, pp159-163) goes on to identify that there is a window of opportunity in which an individual or a company can gain advantage from this change and hence it is important to anticipate what the change will be and when it will occur. Betz (1998, pp159-163) also postulates that the term forecasting is misleading, as technological change is not a natural occurrence like the weather; it is created by deliberate human activity. Therefore, it is more appropriate to refer to it as Technology Anticipation. However, for the purposes of consistency in terminology, the term Technology Forecasting will be retained.

A number of tools can be used either in isolation or collectively, to provide a more “rounded” view to anticipate the trends and changes in technology. These tools have been reviewed in the preceding section and include:

- Committees of Experts
- Complexity Theory
- Delphi
- Discrete Event Simulation
- Technology Focus Groups & Technology Footprinting
- Game Theory
- Nominal Group Technique
- Scenarios
- Technology Trend Models – Technology S Curve
- TRIZ

The Technology Forecast can also identify potential new markets, which may be of interest to the company and also highlight potential threats from substitute technologies.

5.1.4 Technology Review (Internal and External)

Having established the market drivers for the company’s products and services, identified what technology this requires, identified what technological threats exist, and identified how the required technology is progressing, the next step in the process is to review the development capabilities of these technologies both internally and externally. This stage is aimed at looking at how competent the company is in being able to develop the technology, what gaps there are in this capability (this will be important in the next step of

the process) and what the organisation's competitors and potential competitors are capable of.

The tools identified previously that can be used for both internal and external technology reviews include technology auditing and benchmarking. Some of the techniques used to forecast the technology can also be used in the review process, for example, technology roadmapping, technology footprinting and technology trend models.

The review process also needs to look at the technology trends to identify what stage of maturity the technology is at in order to make investment decisions. For example, does the company really want to invest in a technology that is close to maturity, what is the threat from substitution and at what stage does the company wish to withdraw from this technology?

The technology forecasts can also be used to identify (with a degree of uncertainty) when a technology will be sufficiently mature for the marketplace and for inclusion into products and services. If the development profile is too slow for an organisation's market/business plan, the forecast will highlight this gap and the company can take appropriate action to influence the development to meet its agenda.

Having reviewed what technologies the company requires and how capable it is at developing the technology, the organisation is then faced with the challenge of acquiring the technology and in particular the "make-buy" decision.

5.1.5 Technology Acquisition

Technology can be acquired in different ways, which nominally falls into two categories; generated internally (make) and sourced externally (buy). Technology acquisition can occur during the R&D, discovery or invention stage; the innovation stage; or the technology implementation stage, or maturity stage. The methods for acquisition will depend largely upon the stage at which the technology is being acquired and the objectives of the acquiring organisation (Frankel, 1990, p86). Companies are often faced with the "make-or-buy" decision, but how do they go about each and how do they choose between them?

5.1.5.1 Internal Technology Acquisition

No organisation has the resources to develop in-house all the technology its products and services need. Conversely, not all technologies can be bought in. However, it is important to identify which technologies are to be bought in and which will be developed in-house. Floyd (1997, pp112-113) provides a quick guide of how to decide if you should buy-in or develop in-house:

- *Does the technology have a high impact on product performance and hence competitive position? If the answer is yes, outsourcing may make you vulnerable even if the technology is base.*
- *Does the technology influence a high proportion of the product cost? If it does, it is important to remember that outsourcing implies relinquishing control over much of the cost base, again increasing your vulnerability.*
- *Are sources of technology limited, either because there are very few sources, or because switching between sources is difficult? If you buy in a critical technology from a sole supplier, you should be aware that you are offering up a hostage to fortune.*
- *What is the cost of investment, cost of maintenance and the utilisation? (What is the business case for the technology?)*

Having decided which technologies are “core” and should be developed in-house, and having made the business case for developing these technologies, the company’s resources need to be deployed to develop them. The organisation’s structure should also be arranged to support this activity (Metz, 1996, pp118-120).

Once the company has been organised for technology development and the appropriate resources committed, the team that owns this task needs to deploy creative techniques in order to generate the innovation required by such an activity. This can be easier said than done. Some of the tools reviewed in chapter 2 can be used not only for forecasting and reviewing technology trends, but also for generating the creative ideas to advance the technology. In particular, TRIZ (Altshuller, 1998, pp11-21) is promoted as being a “systematic approach to problem solving”.

In addition to problem solving and creativity techniques, various companies and organisations can provide facilitation services, for example structured “brainstorming” sessions, with the technology development teams. They can assist in creating the right

environment and managing the process – freeing up the team to concentrate on the technological problem and its potential solutions.

Another way of developing technology with control, but at a reduced cost and risk is by forming joint venture or research collaborations (Floyd, 1997, pp108-109). The partner could be another company, a research organisation or a university. Selecting the partner is done strategically and may be used as a way of “freezing out” the competition or may include the competition itself – say for an enabling technology.

5.1.5.2 External Technology Acquisition

An organisation can acquire technology through the products and services it procures, by licensing the technology or, as mentioned above, by paying for a research organisation or university to conduct the development by either a joint venture or collaborative research agreement.

Floyd (1997, pp108-109) suggests reasons why one might want to buy in technology. These include:

- The technology may be well developed elsewhere – thus saving time (or they may already have intellectual ownership).
- It can save money.
- Reduces the commitment on internal resources.
- Reduces the risk as external supplier may manage the risks better or have mitigation capabilities.
- The external organisation may have the specialist skills and experience required to develop the technology (i.e. the buying organisation may lack the specialist skills and experience required to develop the technology).

Outsourcing technology development, especially in the form of procured products or services, can come with some risks if the supply is a single source. For example, an organisation that produces the products that one is outsourcing can decide that the outsourced product is no longer financially viable and decide to stop making it, so that it becomes obsolete. Alternatively, the supplier company could go into liquidation also rendering the product obsolete. The author experienced both of these situations whilst

producing aircraft instrumentation, one involving transputers which became obsolete, and the other involving 3-inch Active Matrix Liquid Crystal Displays (AMLCD), where the company went into liquidation. These situations are particularly difficult when a certified product is involved, for example an instrument approved for use in aircraft. In this case the instrument manufacturer has to contend with not only the cost of redesigning the product, but also the difficulty of re-certifying it.

This problem also affects the instrument supplier's customer who is expecting delivery of the product. In some cases of a supplier going into liquidation it may be cost effective, although a burden on resources, for the customer to take over the ailing supplier in order to maintain the source of supply.

The external sourcing of technology is the main focus of this thesis, as opposed to the internal creation. The technology planning and management model to be developed will address the issues associated with the influence an organisation can make over its supply of its out-sourced technology.

5.1.6 Technology Implementation

Once the technology plans are in place and the organisation has decided what technology it needs and how it is going to obtain it, the management will need to structure and organise for these technology activities. This will include the definition of roles that people will fulfil, for example chief technology officer, and what responsibilities they will have.

The technology activities need to be integrated into the business and will need buy-in and involvement from all areas within the business. This can include participation in the decision making process for prioritising technology projects, and participating in the projects themselves.

The implementation phase will also require measures to be put into place to monitor effectiveness. These measures should include the added value to the business, which will be particularly important in justifying the investment to shareholders and other stakeholders.

5.2 Technology Planning & Management Lifecycle Model

Taking the above approach, the following technology planning and management lifecycle model was developed. The issues raised by the study into the instrumentation supply chains and the reviews of the models of the existing technology planning tools were used as inputs. It should be noted that this is a generic model and provides a certain level of abstraction.

The technology planning and management lifecycle model was constructed using the UML version 1.x extension to Microsoft Visio™ and the extensions proposed for business process modelling by Erikson and Penker (2000, pp419-427). Again not all of Erikson and Penker's formats could be adopted due to the constraints of Microsoft Visio™. The model uses the activity, class and state chart diagrams from the UML and adopts the same approach as described in chapter 4. The numbers highlighted in circles are not part of the UML syntax and are only there to reference where in the model the issues identified in the study are addressed, see tables 13 and 21 in chapter 3. The parts of the model that are boxed and shaded, again are not part of the UML syntax and are only to show where each of the existing technology planning tools is incorporated into the model. In addition, the supporting text references to the points raised during the technology tools modelling peer review in chapter 4 are identified by (RP*number*) and the issues raised by the study in chapter 3 are identified by (issue *number*).

The starting point of the model is to take a systems view of technology and to address the fact that technology has a lifecycle from the initial ideas and concepts, resulting from scientific research or a market need, through keeping it fed and to its eventual disposal (issue 41). The technology lifecycle concept is not much different to a product lifecycle. The Technology Planning and Management Lifecycle model is intended to be adapted to suit the organisation implementing it. It is also envisaged that the lifecycle will be repeated periodically, the duration of which will be part of the implementation. Some of the activities described are at particular points in the lifecycle. However, they may need repeating, especially during implementation, if significant changes are made. For example, if the key technologies are changed during the lifecycle the vision will need to be revisited and checks and balances will need to be in place to ensure that technologies previously identified as 'key' are not overlooked.

The risk-level of the technology (like a product) follows a bath tub curve, Figure 28. The risk is initially high and gradually reduces with time as work on the technology matures it, and reduces its uncertainty. The risk of the technology increases as it ages as it becomes a basic requirement to compete rather than providing a competitive advantage. Eventually the technology can become a liability as substitute technologies overtake its performance and provide the competition with a competitive advantage. The aim of the whole process is to address technology planning (issue 48), reduce risks in technology development and hence ensure that poor risk management is not a barrier to innovation (issue 40).

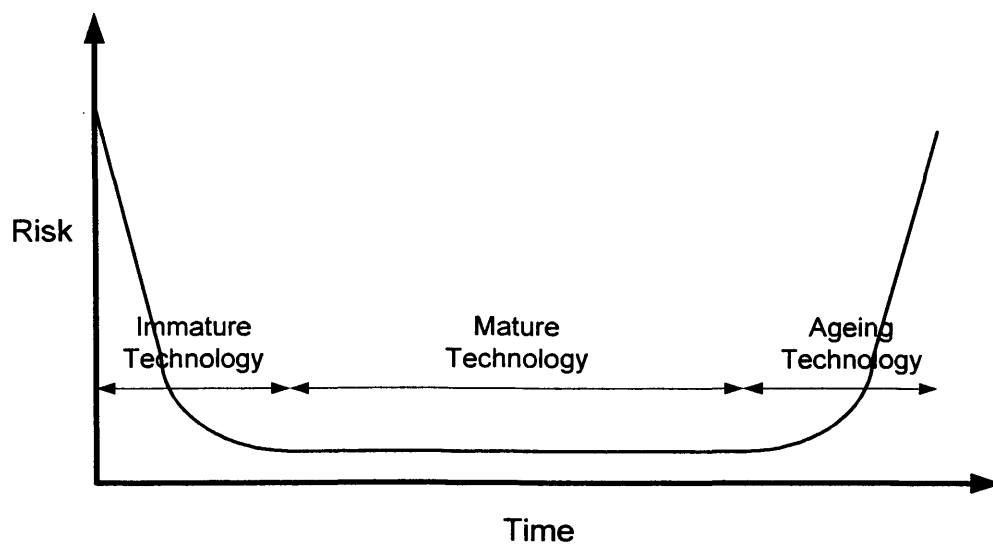
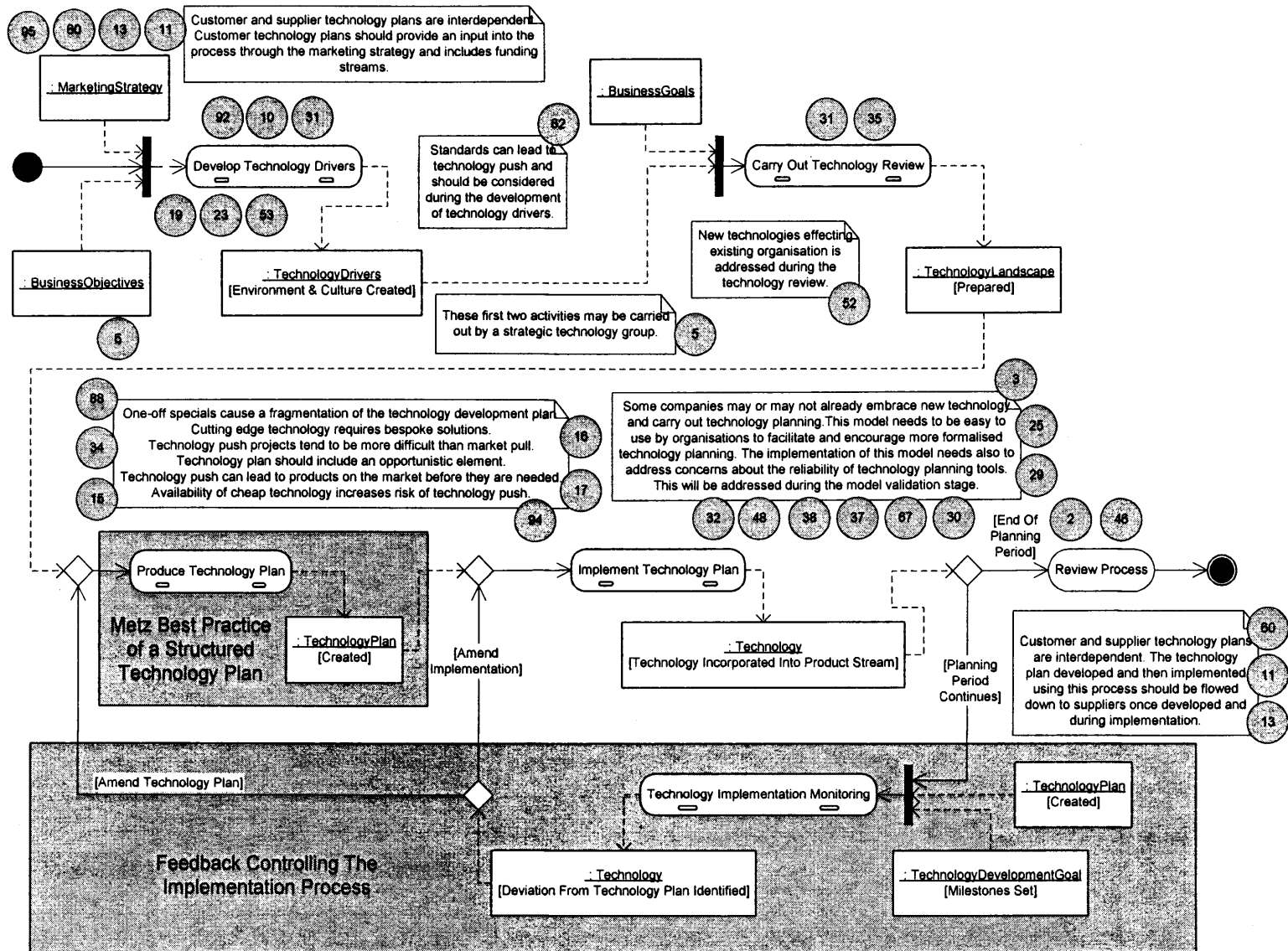


Figure 28 Technology Maturity Risk

The technology planning lifecycle is shown in Figure 29 and the associated class diagram in Figure 30 depicting the relationships between the classes in this lifecycle.



The state changes for technology during the course of its lifecycle are shown in Figure

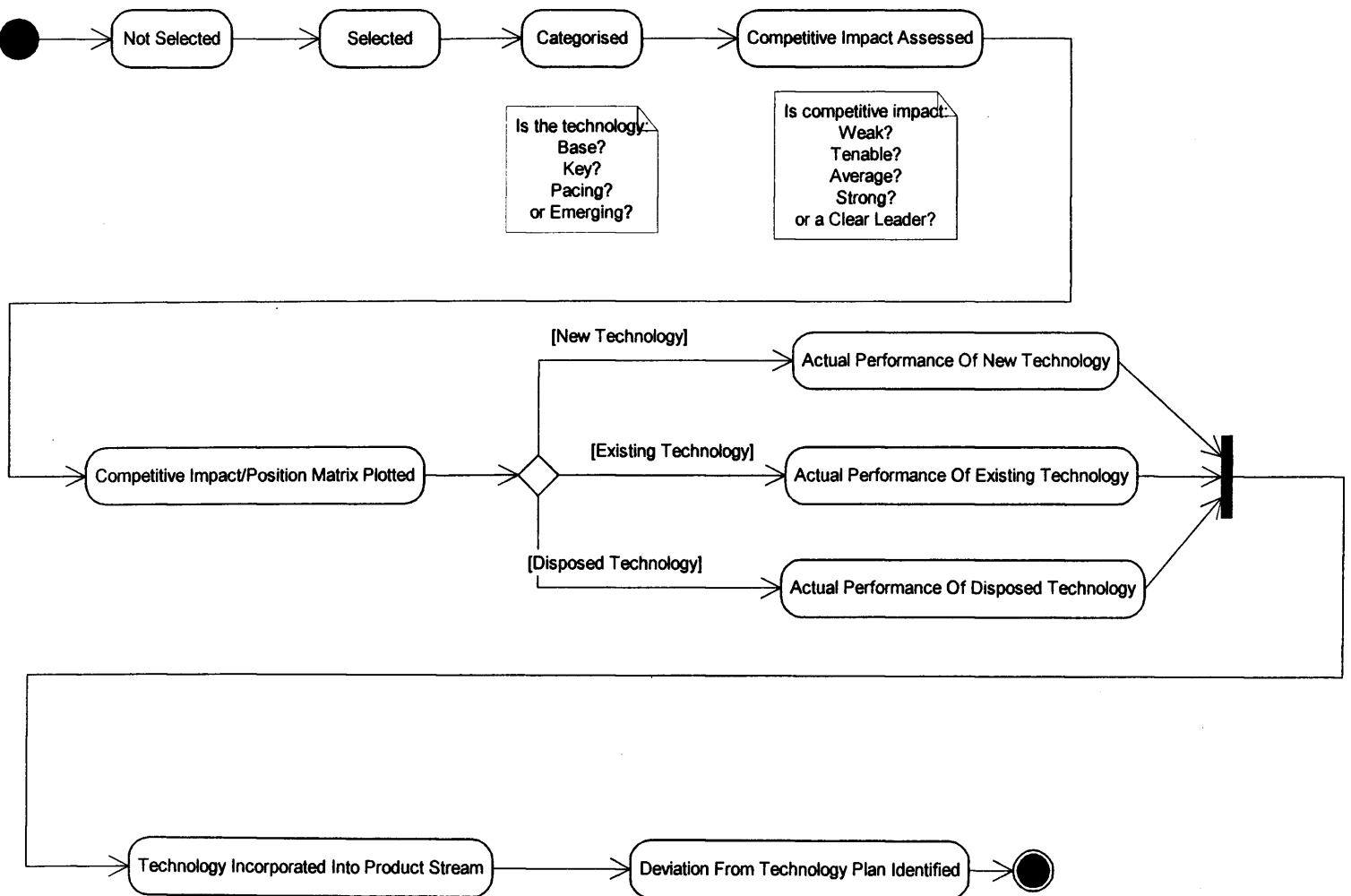


Figure 31 Technology State Chart Diagram
150

The high level lifecycle model follows Pólya's (1945, pxxxvi) 'how to solve it' method; understand the problem, devise a plan, carry out the plan and review (looking back). The lifecycle starts by developing the technology drivers from the business and marketplace needs (the business case for technology needs to be made to higher management and the mismatch between technology and product lifecycles needs to be addressed). The link between the business objectives and the technology drivers is required to ensure there is senior management buy-in to the technology planning and management process. One of the issues raised (issue 80) by the study in chapter 3 was that it is easier to get engineers to buy-in to technology planning than senior management. However, the author believes this is not strictly true as senior management would take a more strategic view than engineers and therefore see its value. Regardless of the outcome of this debate, successful technology planning requires senior management buy-in (issue 79) and requires a champion (referred to as a visionary in the study) to drive it forward (issue 97).

The technology drivers should include: "what information do I need, what are the inputs and outputs, what help is available and what are the costs and benefits?" (RP17). Market and competitor assessment tools are used to provide inputs to the technology plan. These inputs can also come from feedback from the organisation's sales force and maintenance engineers. Customers may also drive and fund technology development within the supply chain (as they need the right products at the right time (issue 86)) and competition drives the time to market. Therefore, the technology plans of customers and suppliers need to address this interdependency. This part of the model addresses issues 6, 10, 11, 13, 56, 60, 68, 92 and 95 from the study described in chapter 3.

Developing the technology drivers also addresses the need for suppliers to be aware of the industry direction, including market trends, and technology, and to ensure technology does not get missold (i.e. technology is linked to customers, markets and products). This addresses issues 19, 25, 31 and 53. Standards can lead to technology push and should also be considered during the development of technology drivers (issue 62).

It is worth noting during this part of the lifecycle that many of the most successful radical innovations were not demanded by customers, for example the Sony Walkman, and instead were the work of technology/product innovators. These disruptive technologies are difficult to predict, initially may not provide an adequate market size for large organisations

and tend not to satisfy existing markets. It is this dilemma (market size versus innovative technology) for large organisations trying to manage technology, which is the subject of Christensen's (1997) work.

A technology review is then carried out to understand where existing technologies are, where the technologies of interest are going and how good the organisation and its competitors are at these technologies (issue 31). The review should also identify threats from substitute technologies (issue 35) and should address the new technologies that will affect the organisation's existing business (issue 52).

These first two activities may be carried out by a strategic technology group within the organisation (issue 5) or by senior management.

From the technology review a plan (one of Metz's Best Practices (1996)) is produced that addresses the technology drivers. The planning stage of the lifecycle needs to address the following issues:

- One-off specials cause a fragmentation of the technology development plan (issue 15).
- Cutting edge technology requires bespoke solutions (issue 16).
- Technology push projects tend to be more difficult than market pull (issue 17).
- The technology plan should include an opportunistic element (issue 34).
- Technology push can lead to products on the market before they are needed (issue 88).
- Early adopters are more enthusiastic about new technology (issue 90).
- Availability of cheap technology increases risk of technology push (issue 94).

Some companies may already embrace new technology and carry out technology planning. The model is intended to be easy for organisations to use in order to facilitate and encourage more formalised technology planning. The implementation of this model needs also to address concerns about the reliability of technology planning tools. This will be

addressed during the model validation stage. This addresses issues 3, 25, 29, 30, 32, 37, 38 and 67.

This planning process should include cost/benefit and make/buy decisions and will usually have a finite duration. Due to the interdependence of customer and supplier technology plans, the technology plan should be passed down to suppliers once developed and during implementation (issues 11, 13, and 60).

The technology plan then needs to be implemented; this should include determining how technology is brought into the business and developed, how it is maintained and how it is to be disposed of. If the plan needs to address the substitution of a technology, then the introduction of the substituting technology needs to be co-ordinated with the disposal of old technology.

The model includes a feedback path that includes monitoring and auditing of the implementation to ensure it is conforming to the plan. Any deviations will result in either an amendment to the implementation or an amendment to the plan.

At the end of the planning period (which can be of finite duration or open-ended) the implementation of the whole technology planning process is reviewed to provide an opportunity for process improvement (issues 2 and 46). It should be stressed that any obvious problems with the implementation of this lifecycle should be addressed at the time of discovery and not held back until this review process.

It should also be noted that this is a generic lifecycle and will require tailoring to the specific business to which it is being applied. Some of the lower level parts of the model may not be required for some applications. Organisations may wish to include phase review gates between the phases of the lifecycle in order to monitor and assess the maturity of the technology as it progresses through the process. These reviews can also include any key decisions that are made and can then be recorded for future reference.

The rest of this chapter will explore each of the phases of this lifecycle in more detail.

5.2.1 Develop Technology Drivers

The first phase of the model is to develop the drivers for the technology. The process is shown in Figure 32 and the associated state change of the technology drivers is shown in Figure 33.

The main inputs to this process are the business objectives and the marketing strategy. The marketing strategy should also indicate potential new markets for existing technologies (issues 59 and 70). However, inputs from market research need to be treated with caution as market research can over estimate demand (issue 84) or under estimate demand for radical innovations. This is largely the problem of carrying out inadequate market research. Any inputs from the marketing strategy should be in the form of capability requirements and not in the form of technical solutions to prevent reducing the options open to the organisation during the whole technology planning lifecycle (issue 76).

The first part of developing the technology drivers is to review the customer needs. This aims to elicit new ideas from customers and users of the services/products (issues 54 & 61). During this review any standards either specified by the customer or required by legislation need to be considered. These standards can lead to a certain amount of technology push and hence should be considered during this part of the process (issue 62).

Using the output from the customer needs review (future system capability) the next step is to identify the key product features that will satisfy those customer needs. This defines the technology capability required to satisfy the customer's needs. Having identified the key product features, a first round of identifying the technology solutions to meet those key product features can be performed. This first round of identifying the technology solutions is used to help identify what technologies are of interest to the organisation. The next major step after identifying the technology drivers is to conduct an in depth review of the technology landscape. To keep this to a manageable and affordable size the technologies of interest need to be identified in advance.

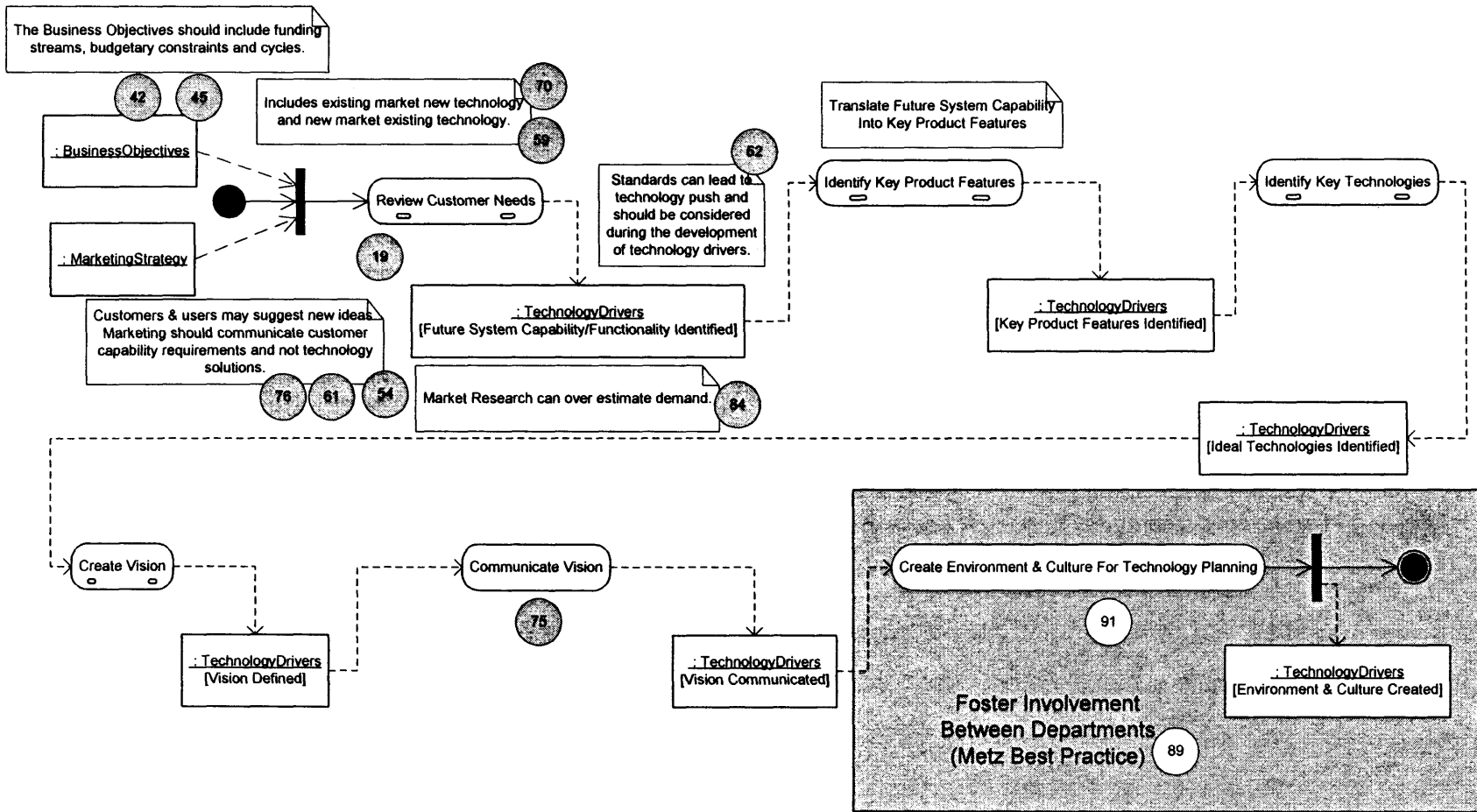


Figure 32 Develop Technology Drivers Activity Diagram

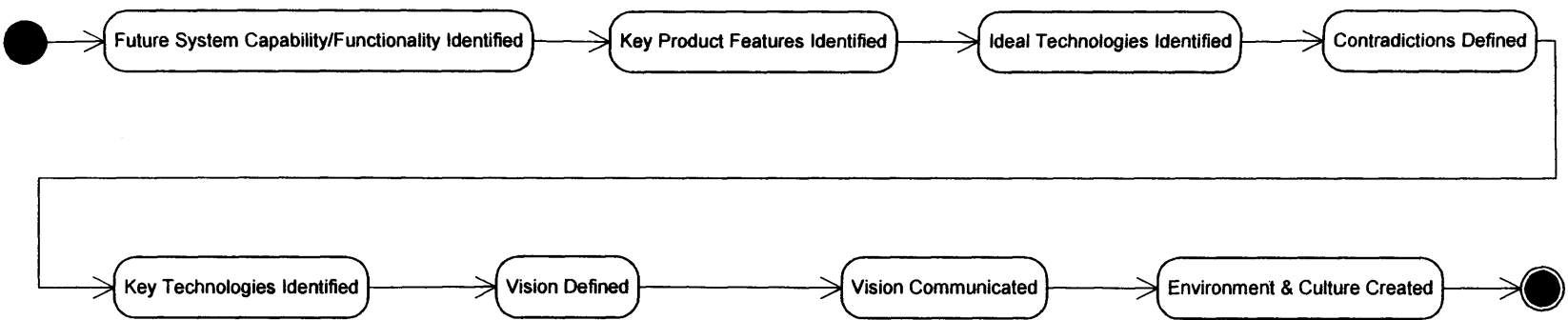


Figure 33 Technology Drivers State Chart Diagram

After identifying the key technologies, a technology vision needs to be formulated and communicated to the organisation (issue 75). The organisation needs to be structured and organised for technology planning. This includes encouraging a culture of technology planning (issue 91) and fostering the involvement in the activity (Metz (1996) best practice) from the different functions from across the business. This involvement and culture is required for those who are tasked with delivering the plan to have a degree of ownership and buy-in to the plan. Also other roles that are influenced by or should influence the plan need to be part of the process, especially to prevent downstream disagreements in its implementation (issue 89).

The development of the technology drivers requires a high degree of input, commitment and buy-in from senior management. This includes the linkage of the technology planning and management to the business objectives and the needs of the organisation and the allocation of adequate resources and the creation of the right culture and environment in which to develop technology.

The following sub-sections explore the phases of developing the technology drivers in more detail.

5.2.1.1 Review Customer Needs

The review of customer needs is shown in Figure 34 (see also Figure 35 for associated class diagram and Figure 36 for the state chart of new market sector). This applies to estimating future needs in an existing market and/or alternative markets for existing offerings.

This part of the model uses the Needs Research and the first part of the Attribute Analysis tools (RP1, 2 & 37). The Needs Research part explores the future needs of the existing market. The process simply elicits the needs from the customer and models these needs to identify future system capability, which feeds into the next part of the process.

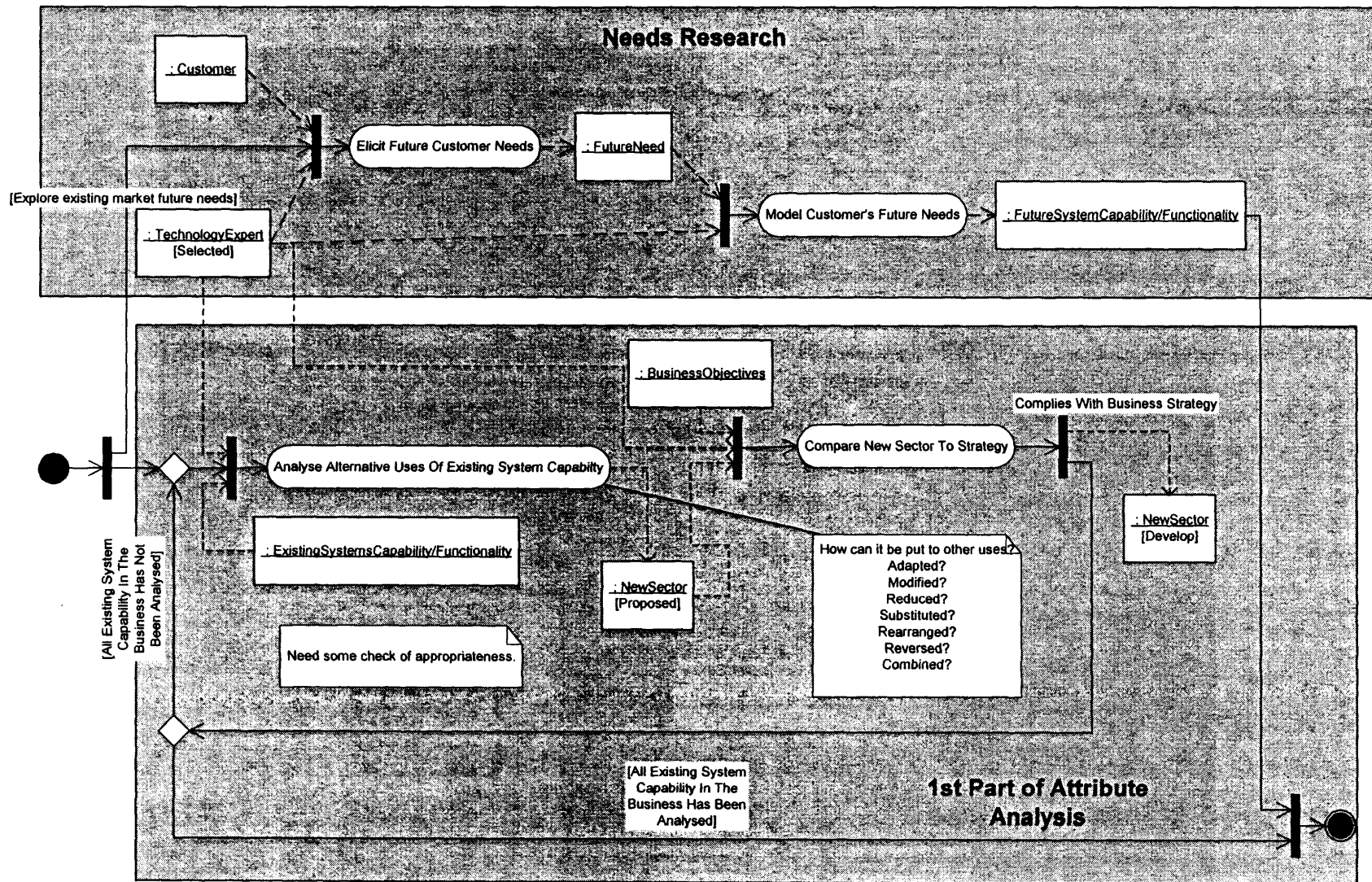


Figure 34 Review Customer Needs Activity Diagram

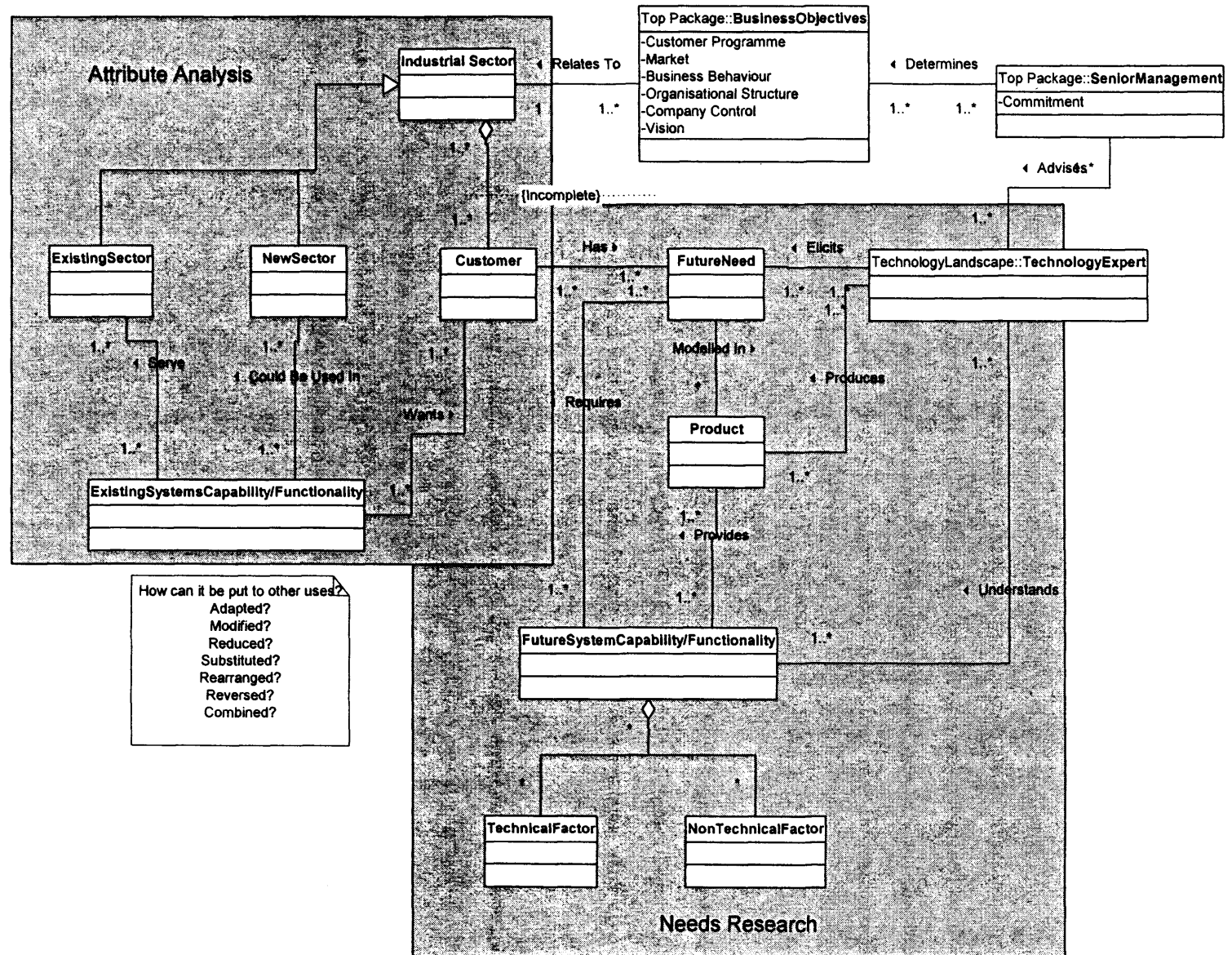


Figure 35 Review Customer Needs Class Diagram

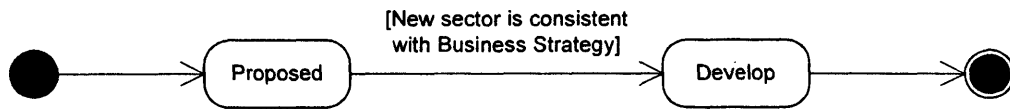


Figure 36 New Market Sector State Chart Diagram

The attribute analysis part of the process explores the existing product/technology offerings in new markets. The new markets identified by the process are compared to the business strategy/objectives and any that fit can be explored as potential new business for the organisation (RP37). This part of the process explores how technology may be transferred between different domains (issue 87).

5.2.1.2 Identify Key Product Features

The process to identify the Key Product Features uses the Morphological Analysis process described previously in chapter 2, see Figure 37 for the activity diagram, Figure 38 for the associated class diagram and Figure 39 and Figure 40 for the associated state chart diagrams.

Morphological analysis starts with the definition of the system configuration (overall architecture) from which the salient features can be abstracted (RP7). Logical alternatives are then generalised for each salient feature. Combinations of these generalised logical alternatives are then analysed by asking “What are you trying to achieve?” “Why are you trying to achieve it?” and linking the solution to value to give suitable combinations (RP8).

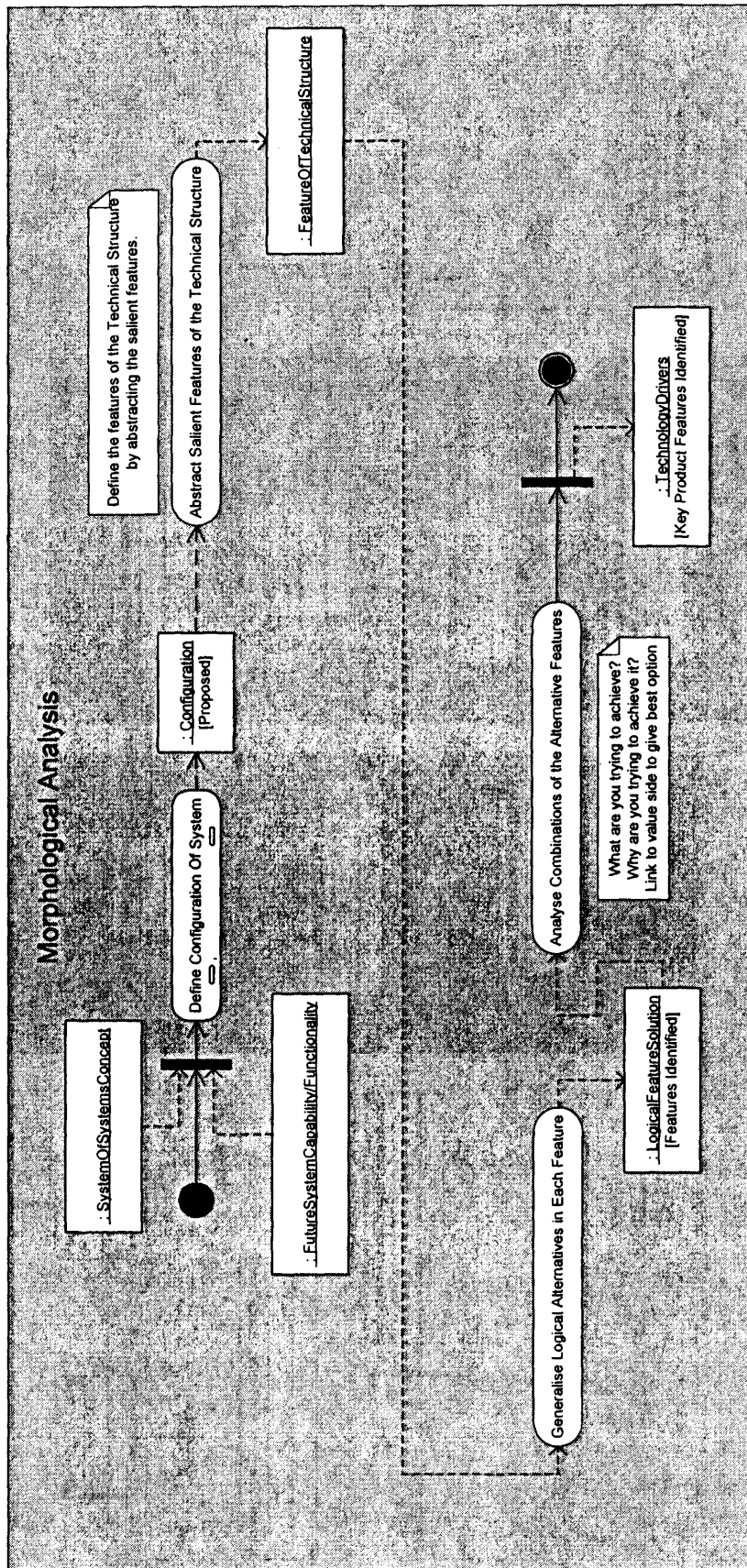


Figure 37 Identify Key Product Features Activity Diagram

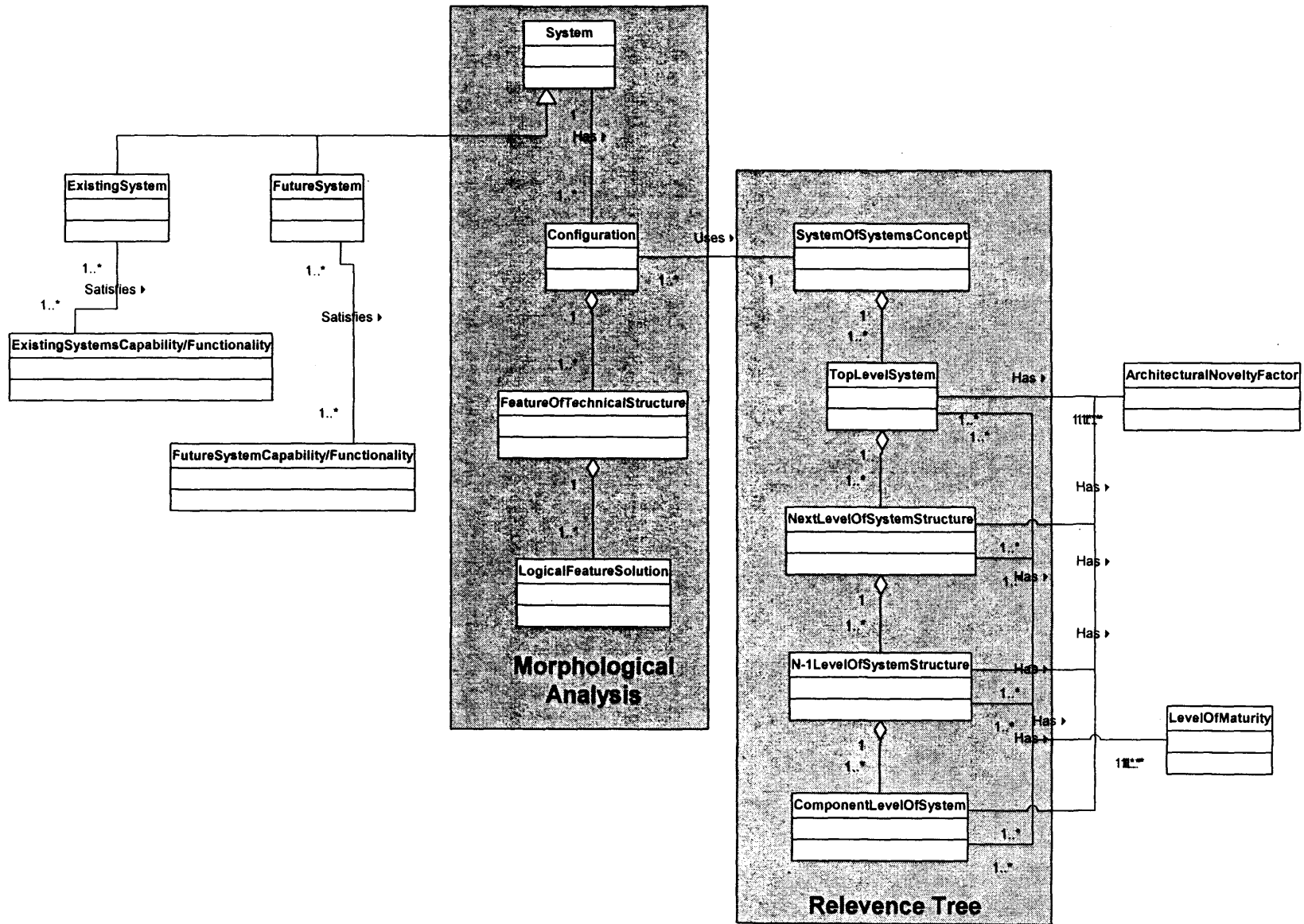


Figure 38 Key Product Feature Class Diagram

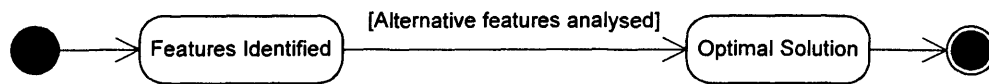


Figure 39 State Chart Of Logical Feature Solution

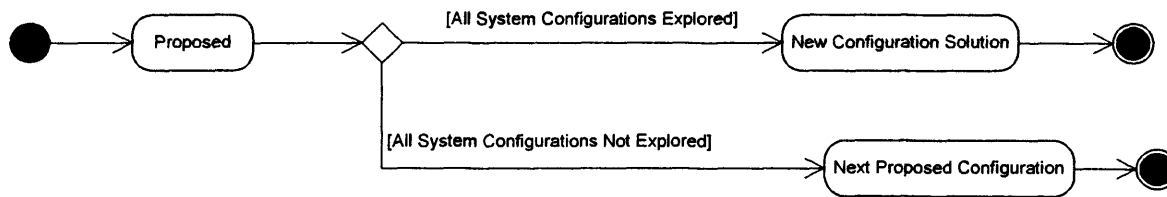


Figure 40 State Chart Of Configuration

5.2.1.2.1 Define System Configuration

The definition of the system configuration utilises the Relevance Tree tool, described earlier in chapter 2 and modelled in chapter 4, to explore the possible options for the system in a hierarchical manner using the system of systems concept (RP34). See Figure 41 for the activity diagram and Figure 42 to Figure 44 for the associated state chart diagrams.

The Relevance Tree technique involves breaking down the system identified by the morphological analysis carried out previously, into logical alternative concepts and exploring potential solutions at each level (RP3). The process continues until all the solutions for all the levels have been explored. During implementation, an organisation may take a view on how many levels and how many potential solutions are explored. Each one of these solutions will contain various technologies and alternative technologies, each with their own maturity (S curve) (RP4). During the planning phase these different maturities need to be considered as it is important to identify which one applies, i.e. is it the system or component level (RP5)?

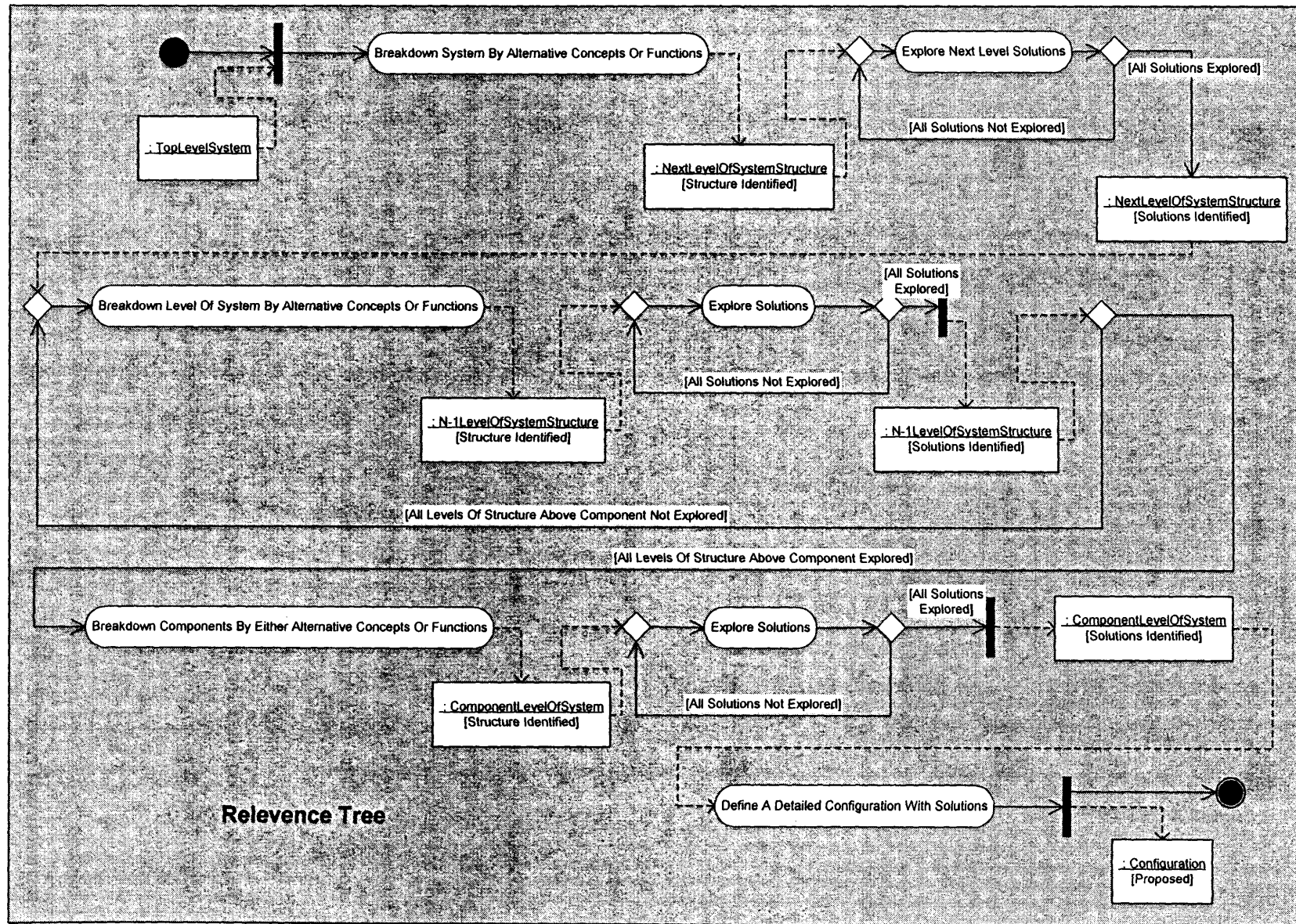


Figure 41 Define System Configuration Activity Diagram

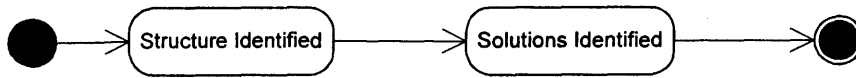


Figure 42 Next Level Of System State Chart Diagram

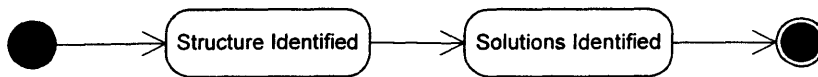


Figure 43 N-1 Level Of System State Chart Diagram

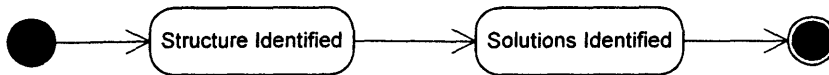


Figure 44 Component Level Of System State Chart Diagram

The position of the technology within the system structure is important as additional factors may influence the natural limit of the technology rather than just the physics of the technology (RP9). For example, at a component level physics will be the main driver for the natural limit. However, at sub-system/system level things like usability may drive the natural limit, e.g. the acceptable weight of a laptop computer, or the speed at which a human operator can respond.

One way of determining which level is important is to use an architectural novelty factor (Cowper et al, 2005) to identify where in the hierarchy the novelty (and risk) applies (RP6).

The use of the relevance tree to break down the system allows the technology planning exercise to focus in on the technologies required to support the system rather than focus on the system itself (RP21).

5.2.1.2.2 Analyse Combinations of Alternative Features

This part of the model reviews the logical alternatives to each feature. The aim of the review is to ensure that these still trace back to the original customer needs by asking “What are you trying to achieve?” and “Why are you trying to achieve it?” for each alternative. It is also worth considering at this point the potential value for each option to enable a priority order to be established for the best option. A QFD diagram, described in chapter 2, can be generated to assist the process of assigning value and priority by combining the customer needs, the business requirements, salient features and the logical alternatives of the system. One of the difficulties surrounding this part of the process is jumping between a capability level and a solution level, as at some point one needs to home in on a solution to enable the process to move forward. It is the Systems Engineer’s dilemma to ensure that solution options are kept open whilst homing in on the optimum solution to allow development to progress (Stevens et al, 1998, pp5-7).

The QFD diagram can provide a basis for the key technology drivers for the organisation that trace back to the customer and business needs. The QFD diagram will be used later on in the technology life cycle process whilst analysing the attributes as part of the technology review process.

5.2.1.3 Identify Key Technologies

The next step to developing the technology drivers is to identify the key technologies required by the product features. The process for this stage is shown in Figure 45 and is derived from some of the elements of TRIZ (RP36) and part of the Technology Footprinting process.

The contradictions can then be resolved by either using the TRIZ techniques for conflict resolution or by internal brainstorming. The removal of conflicts that constrain technology will be useful later on during the technology planning part of the lifecycle when generating the technology roadmaps to identify when resolutions will become available (RP35).

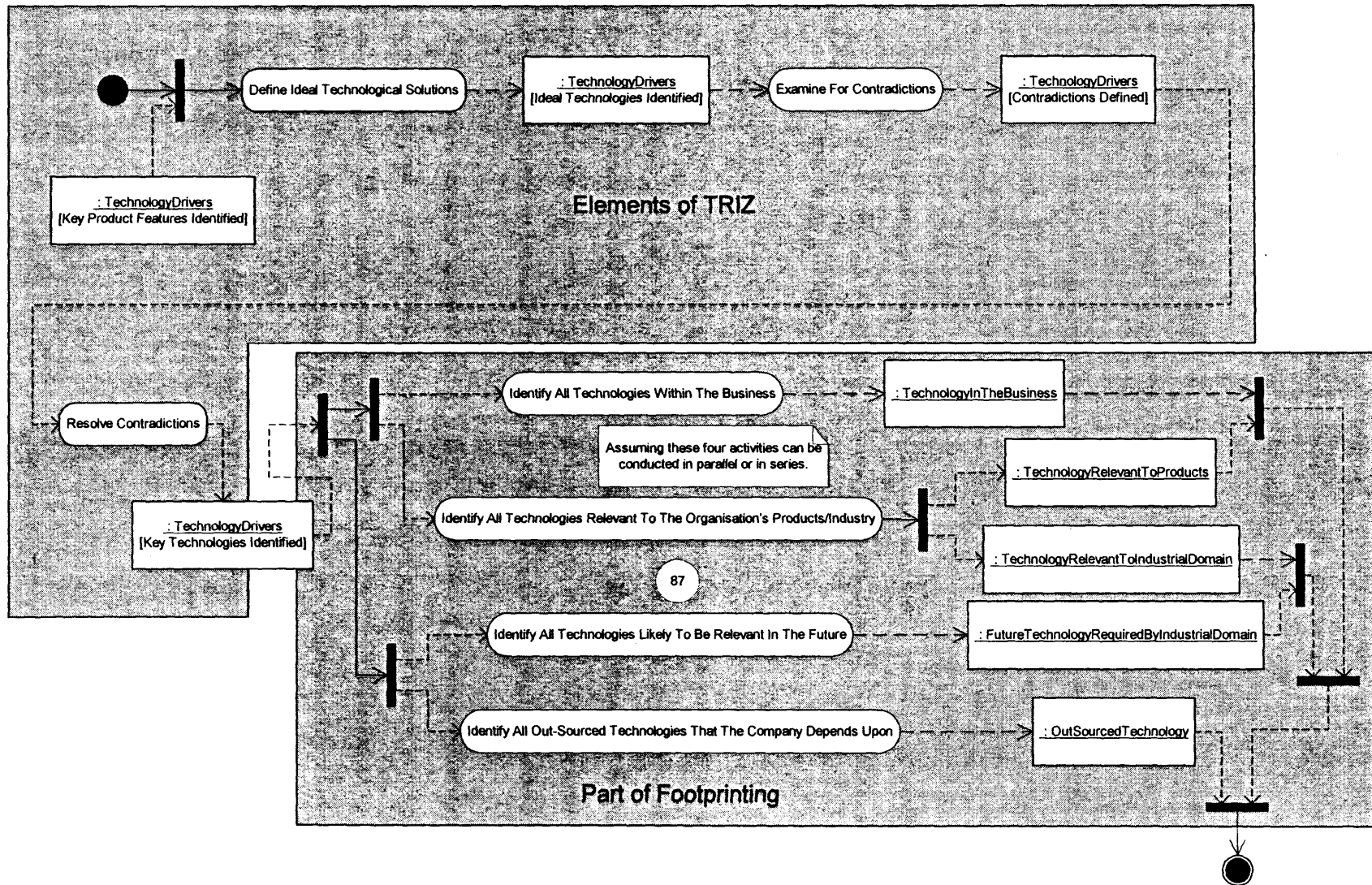


Figure 45 Identify Key Technologies Activity Diagram

The last part of the process after identifying the key technologies is to identify which technologies are available internally and those that can be outsourced. The typical criteria for selecting technologies that can be outsourced will be based on:

- Cost of developing the technology in-house. If this is very expensive one can collaborate with competitors or suppliers to develop the technology.
- The level of competitive advantage the technology provides. If this is high and provides high added value, one would choose to develop the technology in-house rather than out source.
- The level of control over the development process required by an organisation. Outsourced technology means that an organisation may have little or no influence over its development.

5.2.1.4 Create Vision

The creation of the technology vision, Figure 46 and Figure 47, needs to ensure that all stakeholders' needs are addressed for the vision to be balanced and include 'something for everyone'. The vision should also include the technologies that are key to the business and a statement about the importance of the technology to the business. This statement should include the commitment by senior management of resources to making the vision a reality.

The vision needs to be produced in a form that allows it to be communicated across the organisation, for example, uploaded onto the company's intranet site or as posters on the notice board, etc. The vision needs to be re-enforced by actions and behaviours by senior management. For example, although pulling resources from technology development onto problem projects can help resolve short term issues it may be interpreted as an indication that the organisation is not really serious about technology development.

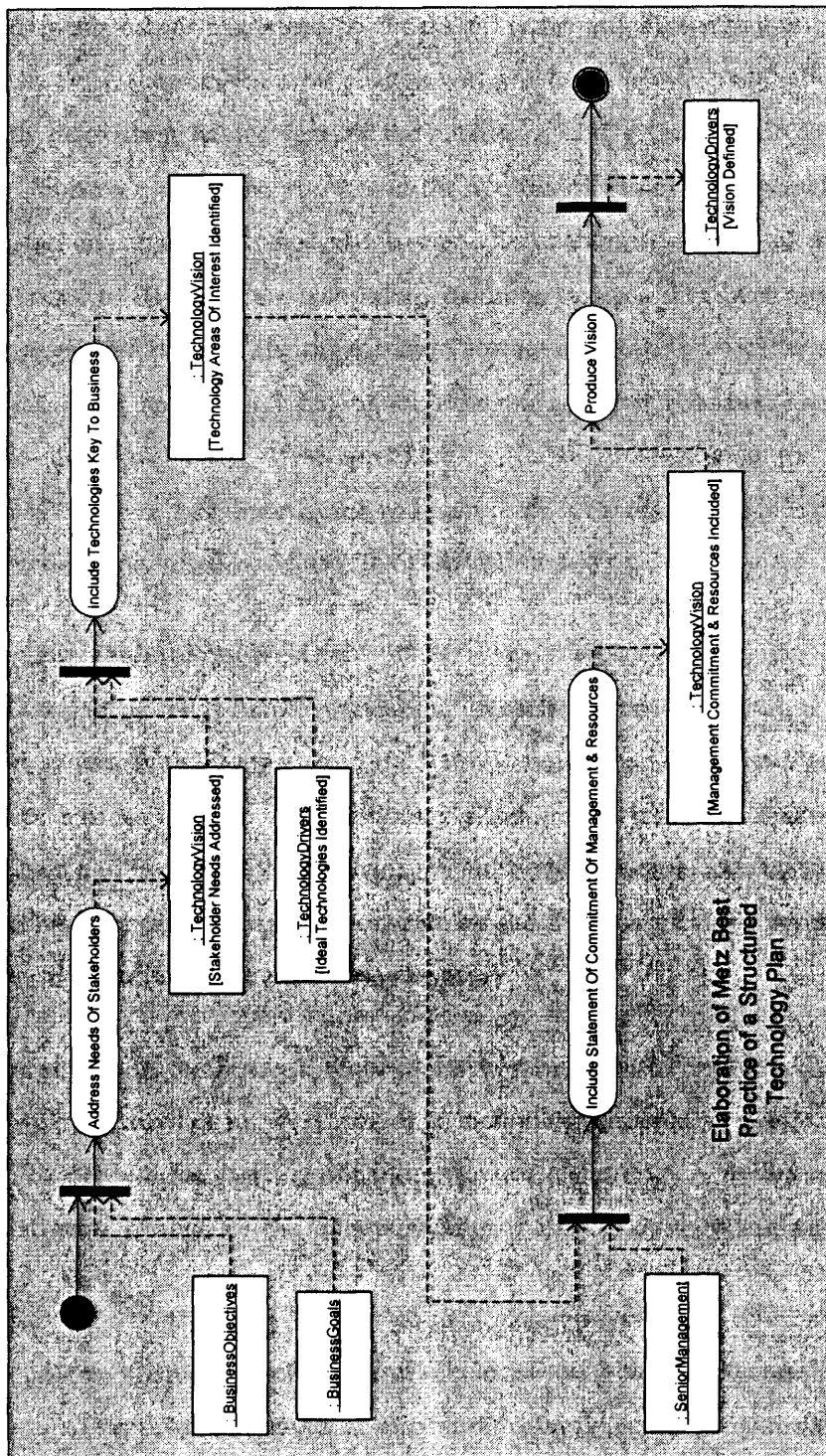


Figure 46 Create Vision Activity Diagram

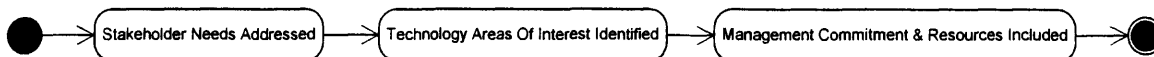


Figure 47 Vision State Chart Diagram

Senior management also need to create an environment and culture for technology planning. Any organisational cultural change will not happen over night due to barriers to change, such as existing habits, fear of the unknown and group inertia (McKenna, 1994, pp493-496). However, using the vision and the actions of senior management this will be a catalyst to start making the change. To sustain the change in culture, all the parts of the organisation need to buy-in to the technology planning process. The best way to achieve this buy-in is to engage all parts of the organisation so that they take ownership of their input to the process and they feel they are having an influence on what goes on (Torrington & Hall, 1995, pp476-481) (McKenna, 1994, pp102-105) (RP47). This involvement between the different parts of the organisation needs to be fostered by senior management and is one of the 'Best Practices' identified by Metz (1996) (RP46, 48 & 49).

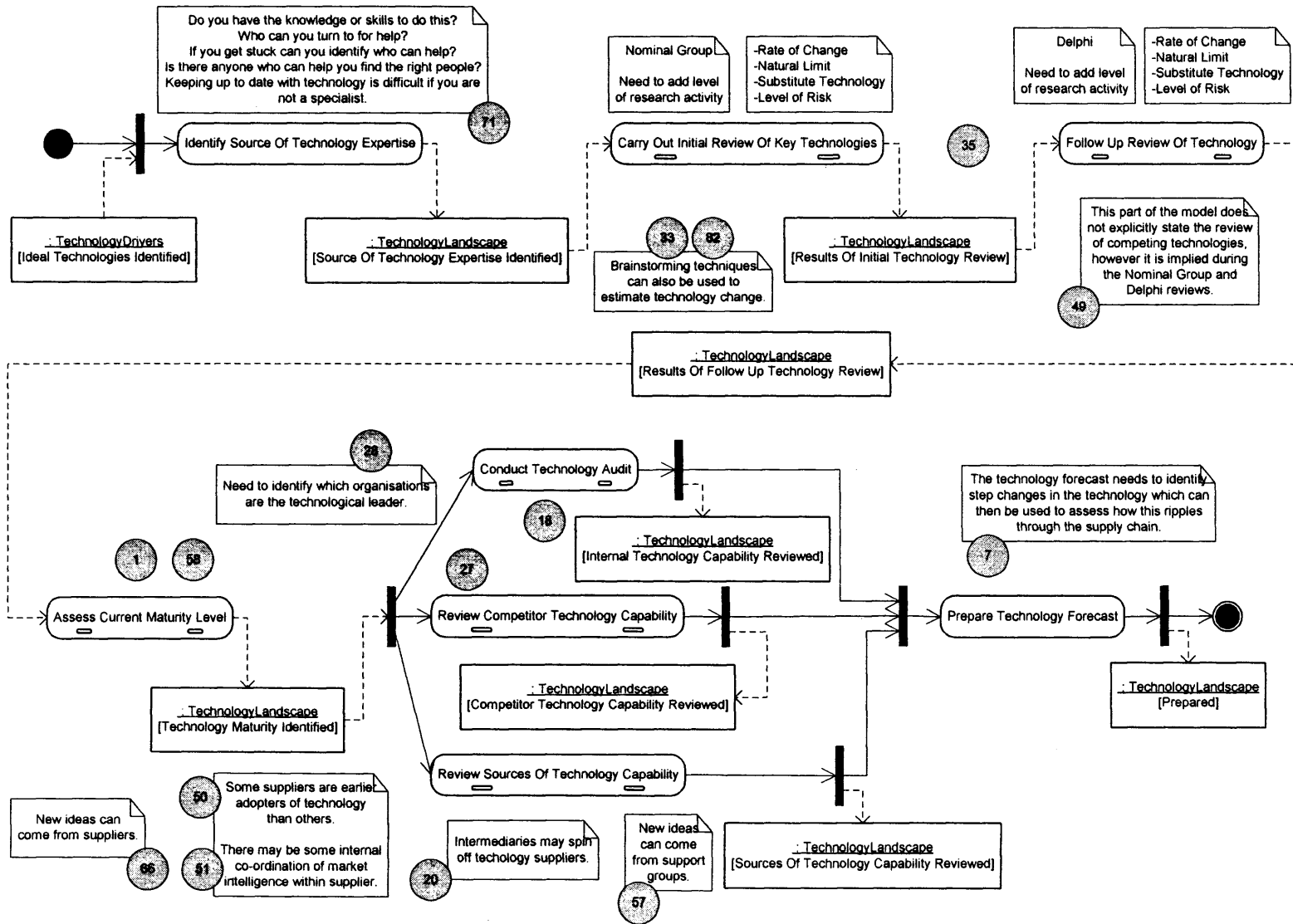
5.2.2 Carry Out Technology Review

The first part of the technology planning lifecycle, already discussed, is mainly a senior management activity with support from the various functions across the business. This part of the process' aim is to ensure that technology development is linked to generating value for the organisation and hence has senior management buy-in (another one of Metz (1996) 'Best Practices'). This first stage is used to home in on the technologies of interest to reduce the amount of work required in the technology review.

The next step in the lifecycle requires the commitment of more resources to put the detail onto the key drivers in the form of a technology review to produce a technology landscape. The process for carrying out the review of technology is shown in Figure 48 and the associated state change of the understanding of the technology landscape is shown in Figure 49.

This process requires technological expertise in the key technologies identified previously and any appropriate potential substitute technologies to provide valuable input for technology decision-making. The first step is to identify and secure the services of this expertise. This may include a combination of both internal and external sources which includes both academia and the commercial sector (issue 96). At this stage it is important to identify potential suppliers and engage with them in this process as supplier technology developments rely on customer interest and/or funding streams and/or customer programmes.

Figure 48 Carry Out Technology Review Activity Diagram



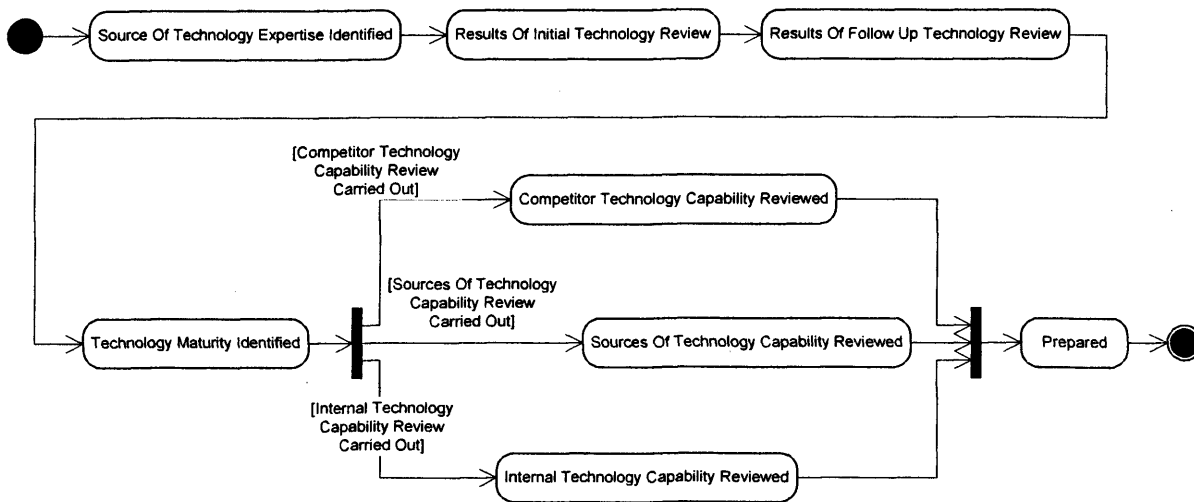


Figure 49 Technology Landscape State Chart Diagram

The organisation needs to ask the following questions (issue 71):

- Do you have the knowledge or skills to do this?
- Who can you turn to for help?
- If you get stuck can you identify who can help?
- Is there anyone who can help you find the right people?

The next two steps in the Technology Review involve an initial and follow up review of technology to establish:

- Rate of Change
- Natural Limit
- Competing Substitute/Alternative/Enabling Technologies (issues 35 and 49)
- Competitive Impact & Position
- Level of Risk

The initial review of technology uses the Nominal Group Technique and the follow up review uses the Delphi Technique. Both of these techniques have already been discussed in chapter 2 and modelled in chapter 4. These two steps are not compulsory and one or both may be omitted given the specific circumstances of the implementation of the technology

planning model. For example, given the limited resources of some organisations, simple brainstorming sessions may be sufficient (issues 33 and 82). The decision whether to use one or both techniques is a cost-benefit trade-off that an organisation has to make.

The results of the technology review are used to assess each technology's maturity (issue 1) including competitive impact and position (issue 58). The assessment of technology maturity uses the Technology Readiness Levels discussed in chapter 2. The competitive position and impact uses the Technology Footprinting discussed in chapter 2. The focus group part of this technique may or may not be required depending on whether it has been covered in the initial and follow up reviews.

Once the maturity and competitive impact of the technology has been assessed, the next step is to review how successful your organisation is at each technology, how good your competitors are and where other sources of the technology may be within the supply chain. For example, new ideas can come from industrial support groups (e.g. Precision Farming Alliance) (issue 57) and intermediaries may spin off new suppliers of technology (issue 20).

Reviewing an organisation's own technology capability is carried out using the Technology Audit technique discussed in chapter 2 and is used in the technology plan to address the specific technology capabilities required (issue 18). Assessing an organisation's competition's capability in the technology allows you to understand how you compete with them. However, if the technology does not provide a competitive edge because it is not core to the organisation's business, the organisation may wish to collaborate with its competitors to spread the risk and the cost. An organisation's competitors can also be a source of new ideas (issue 27).

An organisation's supply chain can be a good source of market intelligence (issue 51) including what their competitors are doing as well as providing new ideas (issue 66). Working with the supply chain requires a delicate balance between market pull and technology push. From the study in chapter 3, too much market pull means that little innovation comes from the suppliers. Instead they sit and wait to do what the customer tells them. Also from the study, too much technology push means that technology is deployed without a specific use and business case. This leads to customer/user dissatisfaction and undermines any potential future benefits of the technology.

An organisation's capability, competitor information and other sources of technology within the supply chain are required during the cost-benefit decision making during the planning phase of this lifecycle. This information will include who the technological leaders are (issue 28) and who the early adopters of the technology are (issue 50).

The last part of the Technology Review process is to compile all the information about the Technology Landscape into a Technology Forecast. The technology forecast also needs to identify step changes in the technology which can then be used to assess how this ripples through the supply chain during the technology planning stage (issue 7).

5.2.2.1 Carry Out Initial Review Of Key Technologies

The initial review of key technologies requires a panel of experts and uses the Nominal Group technique described in chapter 2 see Figure 50 and associated class and state charts diagrams Figure 51 to Figure 53.

The use of the Nominal Group technique at this point is useful if ideas are not well formed and quantitative (RP25). The method is useful as it can be concluded in a single day (RP24). Using this technique, with the caveat that the top solution may be influenced by the personalities involved (RP23), will help you to formulate the questionnaire for the follow up review using the Delphi Technique. Using a follow up technique will help reduce the influence of the personalities involved in the Nominal Group (RP26). The review should include some estimates on the rate of change of the technology, what the natural limit is, what potential substitute technologies there are and the level of risk associated with the technology. The review also needs to include the level of research activity into the technology (this may be difficult to define). These considerations will be revisited by the follow up technology review.

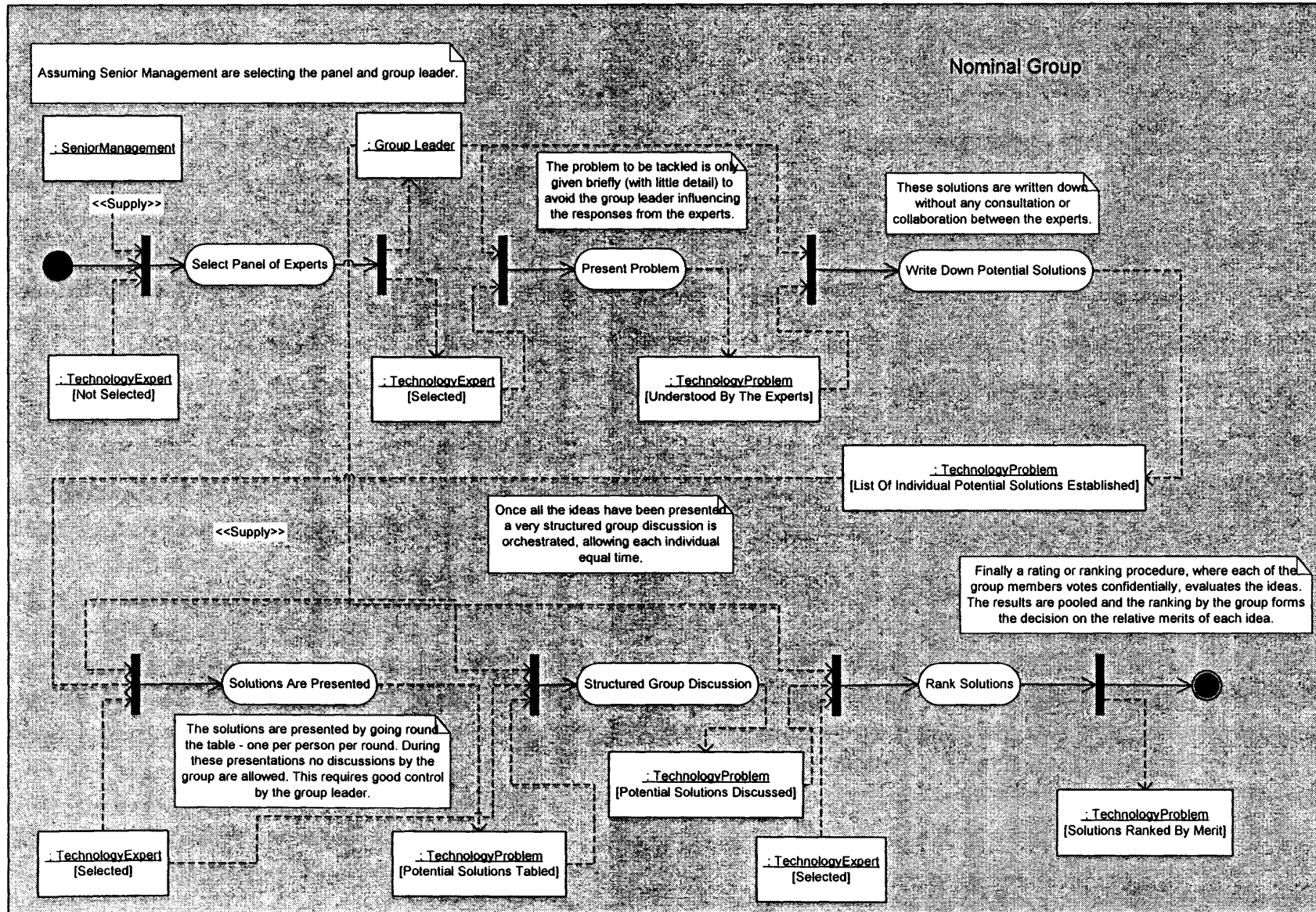


Figure 50 Initial Review Of Key Technologies Activity Diagram

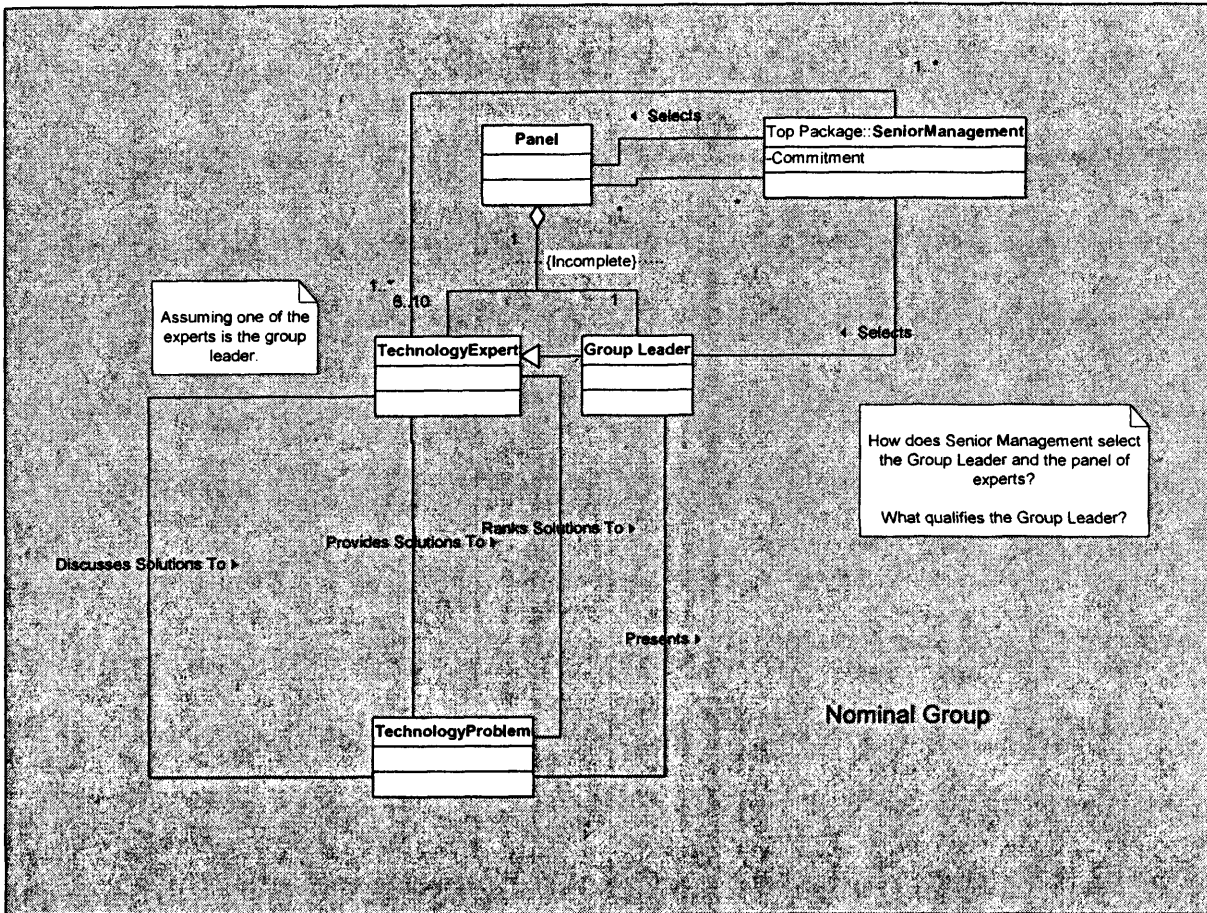


Figure 51 Initial Review Of Key Technologies Class Diagram

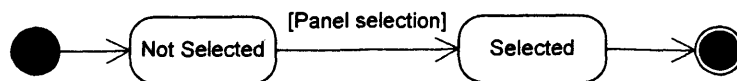


Figure 52 Technology Expert State Chart Diagram

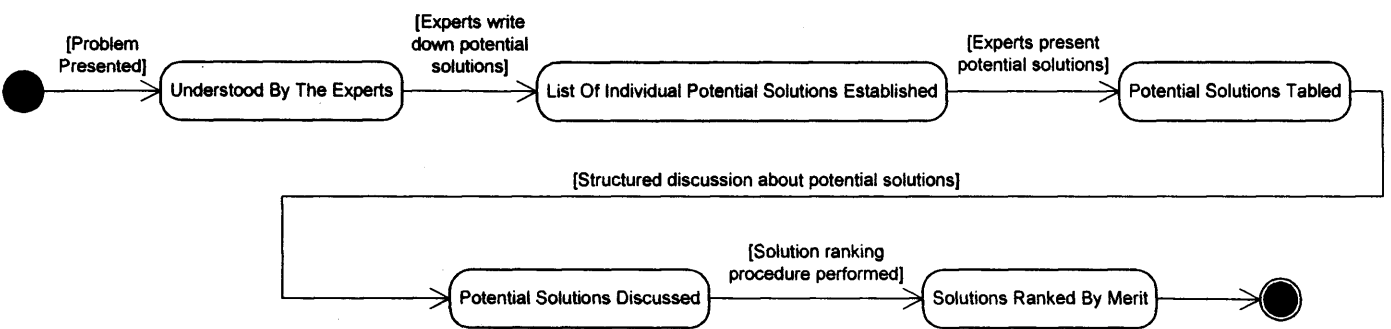


Figure 53 Technology Problem State Chart Diagram

5.2.2.2 Follow Up Review Of Technology

The follow up review of technology explores the predictions and estimations made by the experts more closely. Any deviations from the consensus of experts are reviewed to understand why there are differences. This review again involves a panel of experts and uses

the Delphi technique described in chapter 2 (see Figure 54 and associated state chart and class diagrams Figure 55 to Figure 57).

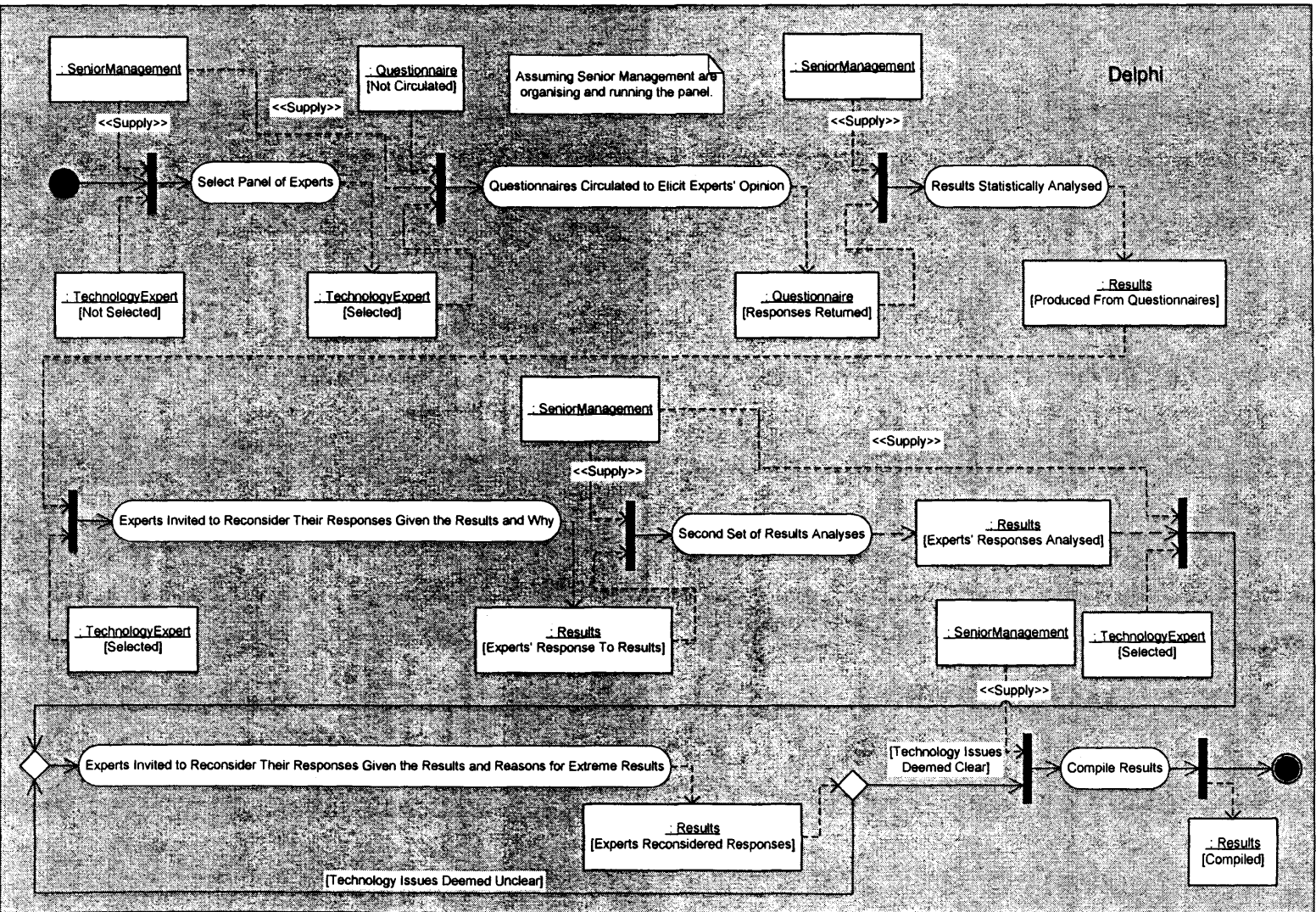


Figure 54 Follow Up Review Of Technology Activity Diagram

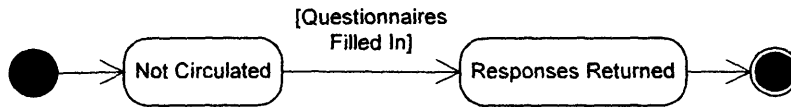


Figure 55 Questionnaire State Chart Diagram

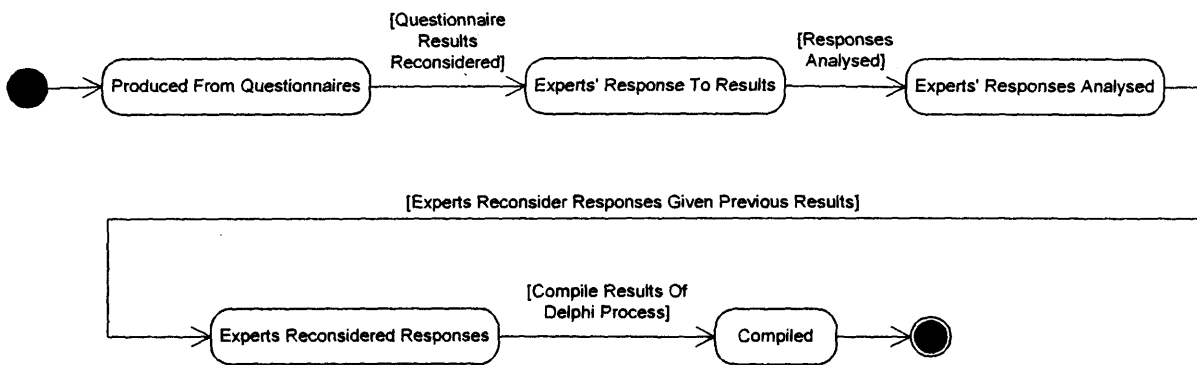


Figure 56 Results State Chart Diagram

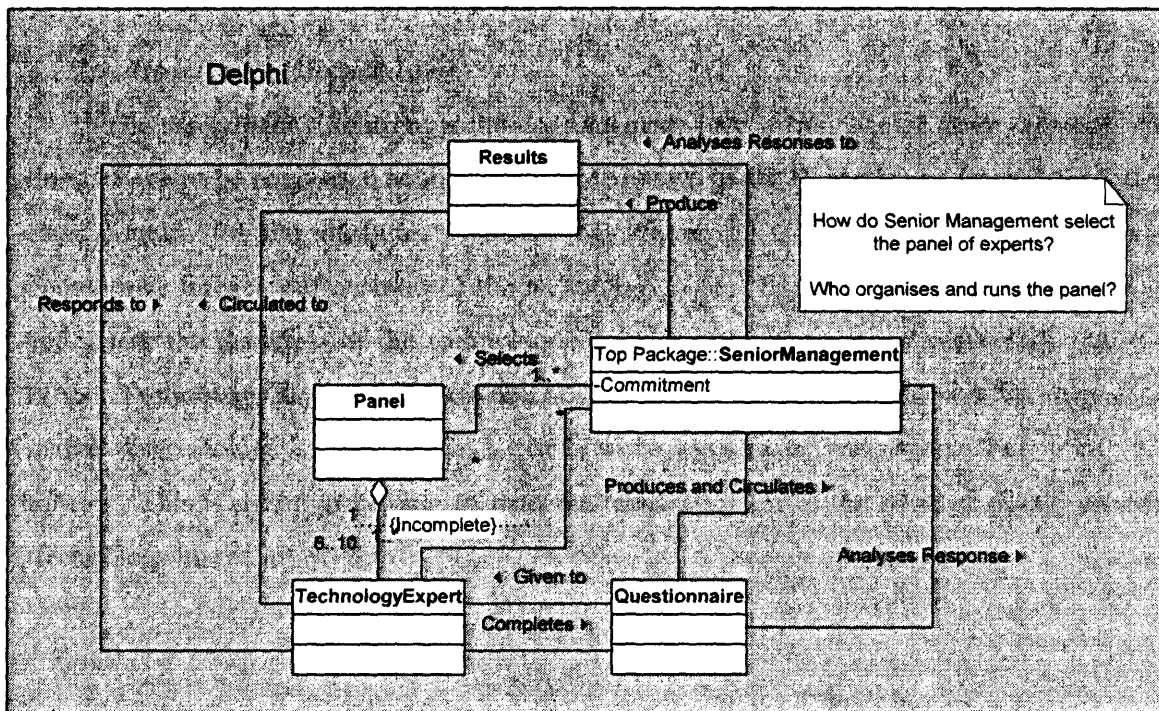


Figure 57 Follow Up Review Of Technology Class Diagram

This technique requires a lot of effort and may therefore be restricted to a large organisation with access to adequate resources (RP13). One will need to assess the costs and benefits of using this technique.

When using this technique, one will need to select the experts from the sources of technology expertise identified earlier and may include both internal and external experts (RP15). The background and status of the experts may still lead to conflicting ideas (RP11) which need to be carefully reviewed when processing the results. The number of experts available will be a limiting factor in selecting the panel size. Small numbers of experts may distort the statistical processing of the questionnaires. Care will also need to be used when conducting the following iterations of the process and challenging the experts' responses in light of the results of the first set of questionnaires (RP10).

The questionnaire design is very important in that the responses to the questions will only be as good as the questions themselves (RP12). Using the information gathered during the initial review to help design the questionnaire is very important. The questionnaire should also address some estimate of market size (RP14), customer/business benefits of the technology and risk (RP16).

5.2.2.3 Assess Current Maturity Level

The assessment of current technology maturity level comprises of three activities that do not have to be conducted in any particular sequence (issue 1), see Figure 58 and associated class diagram for the attributes of technology Figure 59. These activities are: assess the competitive impact and position of the technology; assess the rate of change of technology and assess the readiness of the technology. Assessing the readiness of technology uses the NASA Technology Readiness Levels described in chapter 2 to determine how far away from market a technology is, or in NASA's case how far away from being successfully used on a mission. This is useful in helping to map the technology on to the product design process (technology insertion) (RP45).

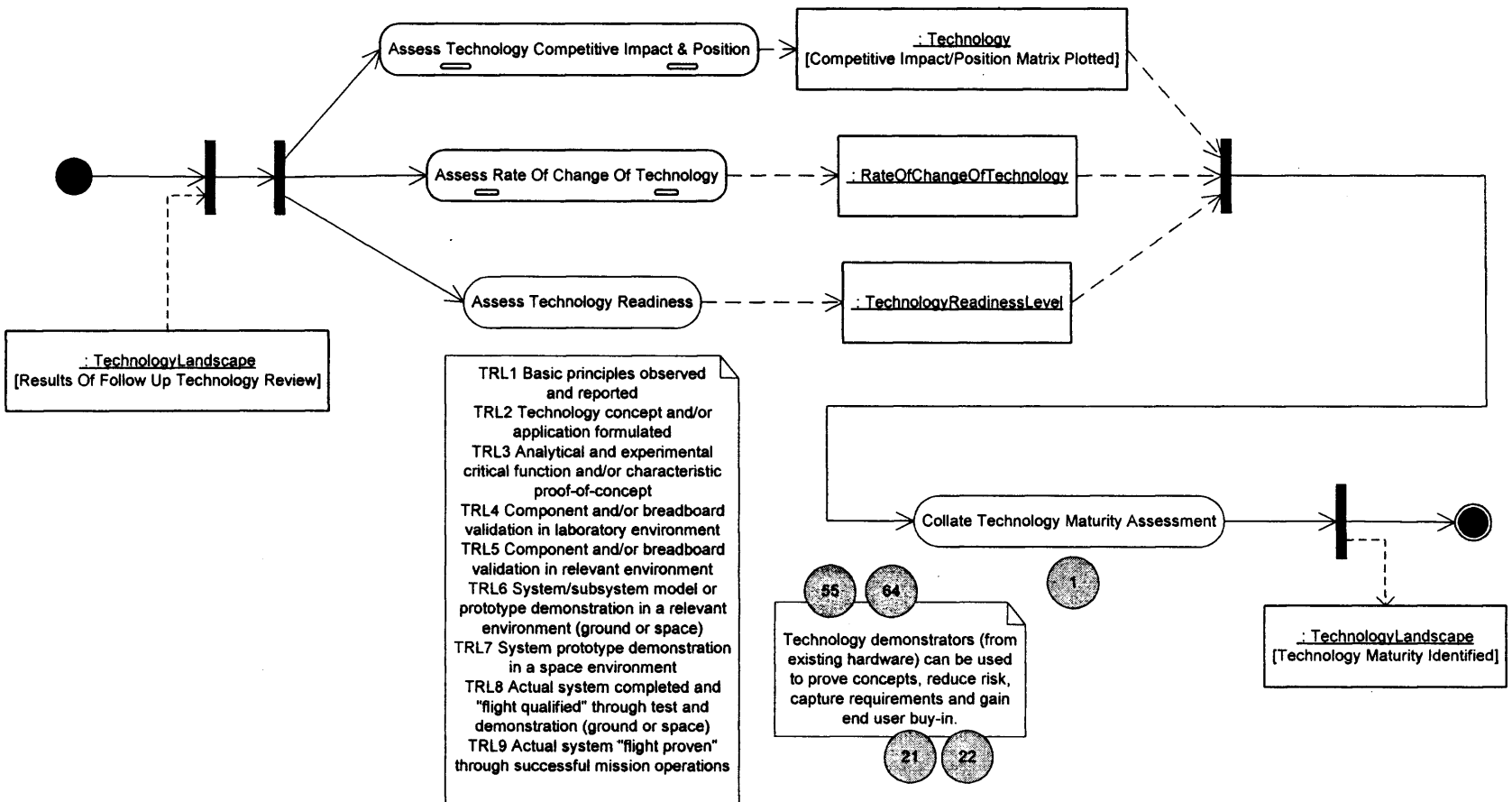


Figure 58 Assess Current Maturity Level Activity Diagram

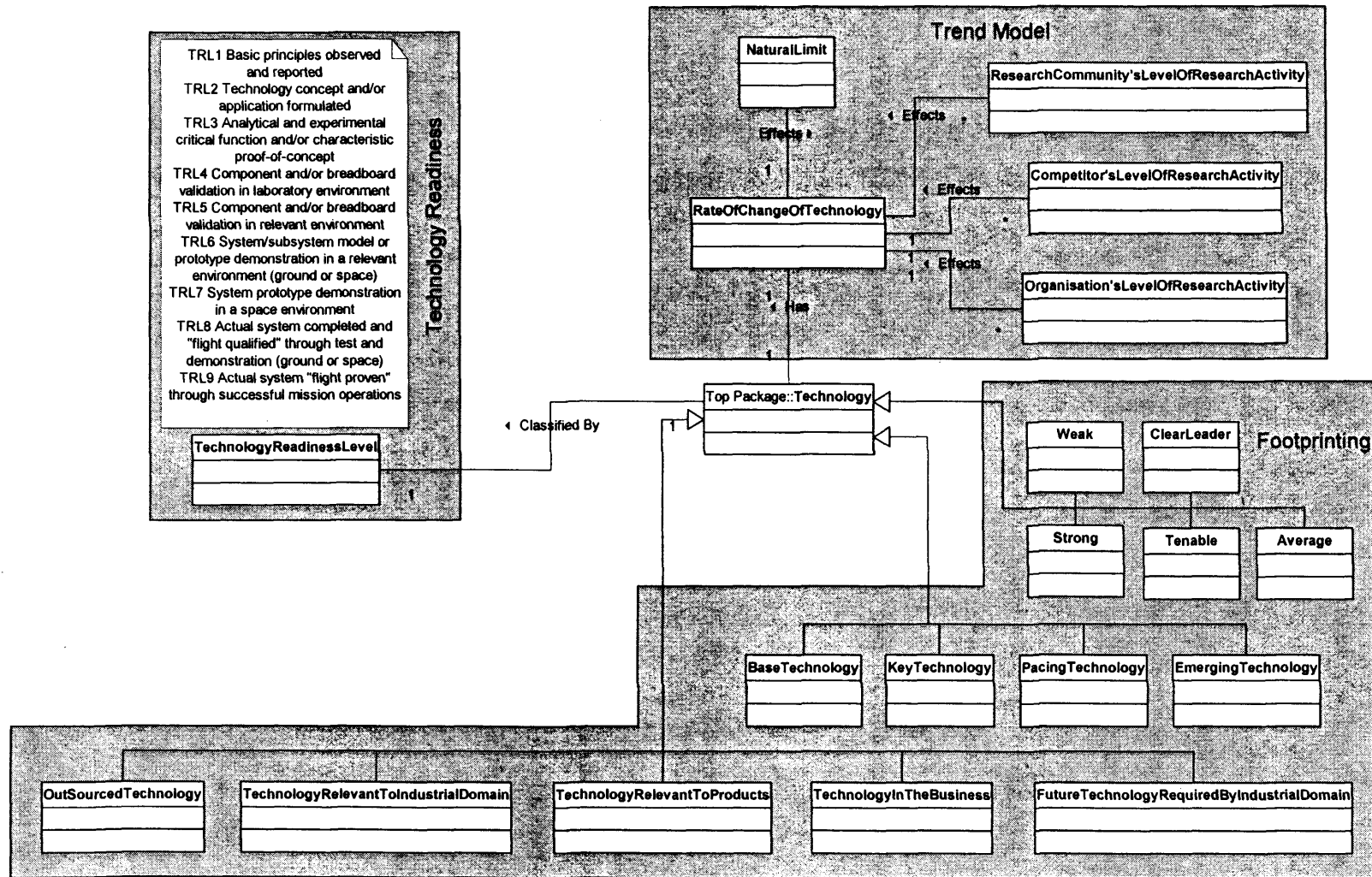


Figure 59 Technology Attributes Class Diagram

The final part of assessing current maturity level is to bring together the three assessments to determine how close to market the technology is, what its competitive impact is and what the current rate of change is (RP18). This information will be used later to assess when the technology will become useful to the organisation, when it will give a competitive advantage and how (if at all) the organisation can influence this development to suit its own plans (RP19 & RP20). For example what happens if I don't get involved in researching this technology? This information is also required during product development lifecycles at the design review gates. The design review will not only need to assess the design maturity of a product or service, but also the technology and risk maturity. This issue is currently being explored by the UK Ministry of Defence as part of a Systems Engineering review of their CADMID (Concept, Assessment, Development, Manufacture, In-service and Disposal) cycle. Technology demonstrators (from existing hardware) can be used to prove concepts, reduce risk, capture requirements, gain end user buy-in and provide an input to design reviews (issues 21, 22, 55 and 64).

5.2.2.3.1 Assess Technology Competitive Impact and Position

To assess a technology's competitive impact and position, the 'Footprinting' technique described in chapter 2 is used, see Figure 60 for activity diagram.

This technique identifies all the technologies within the business, all the technologies relevant to the business' products and industry, all the technologies likely to be relevant in the future and all the technologies that are out sourced. It is determined whether the technology is base, key, pacing or emerging and its competitive impact is assessed as weak, tenable, average, strong, or a clear leader. The technology is then plotted on a competitive impact/position matrix.

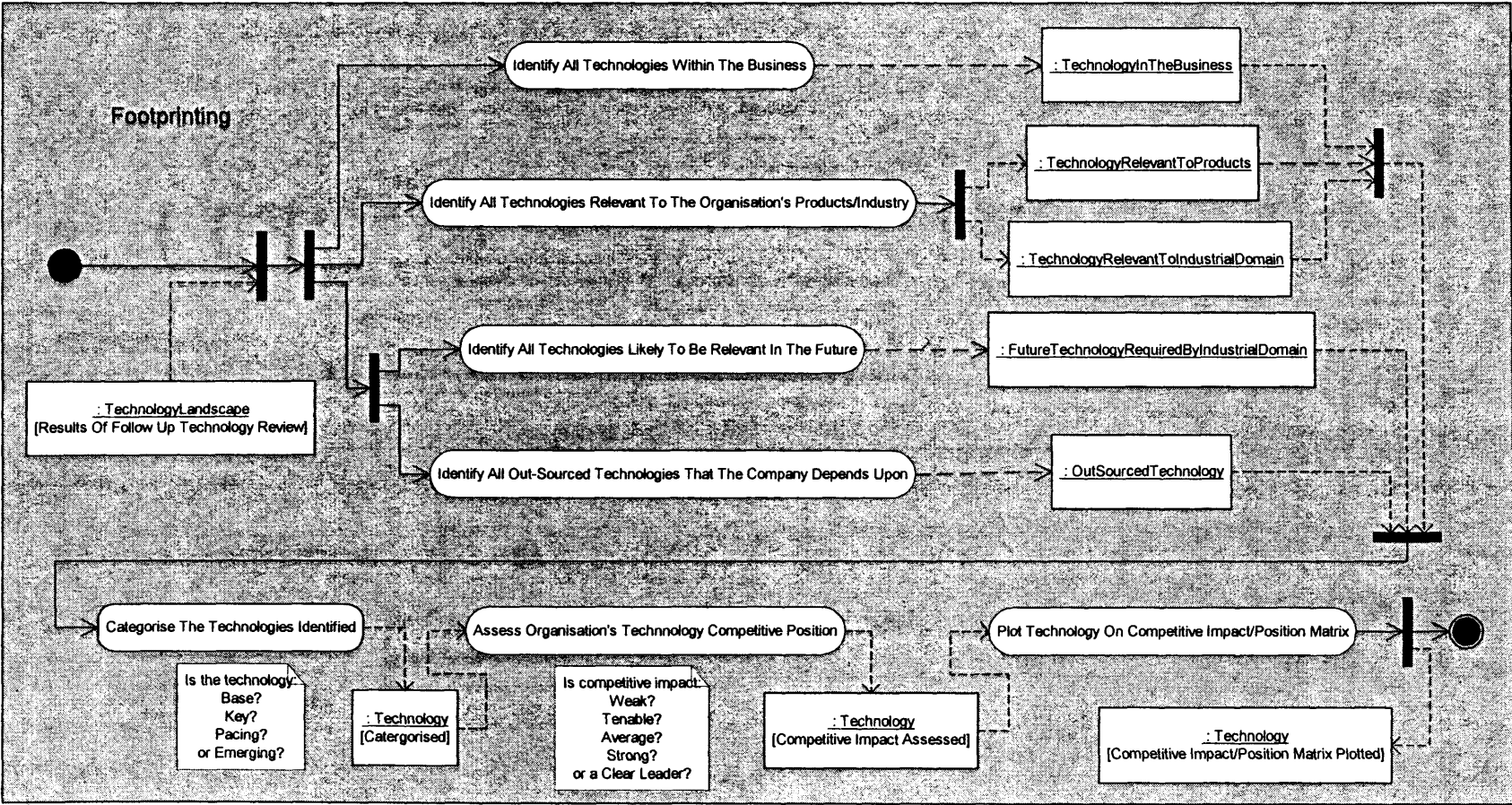


Figure 60 Assess Technology Competitive Impact And Position Activity Diagram

The rate of change is important in assessing when the technology will be mature enough to be incorporated into the company's products. Any differences in the technology's maturity and when the organisation is expecting to incorporate the technology can be considered a technology gap. The organisation also needs to know at what point the technology is in its life cycle in order to assess what its investment decision should be. An organisation does not want to invest in a technology that is towards the end of its lifecycle. Equally the organisation might not want to invest too early in the lifecycle due to the risky nature of immature technology.

However, there are limitations with using the trend models, eg the 'S' curve, as already identified in chapters 2 and 4. Trying to predict exactly where the technology is on the curve can be misleading (RP30). There are too many influential factors which are beyond the control of the organisation (RP33). However the trend model can be a useful reflection tool to explore what happened historically (RP32).

5.2.2.4 Conduct Technology Audit

The technology audit is described in chapter 2 and modelled in chapter 4 see Figure 62 for the activity diagram and Figure 63 and Figure 64 for the class and state chart diagrams. The process simply identifies the technology to be audited, assesses the organisations ability to deliver it, compares the organisation's practices to best practice and then formulates a technology action plan. In this case the technology action plan is fed into the planning phase of the technology lifecycle to inform the decision making process.

The audit should aim to answer the following questions:

- What technologies does the company possess?
- Where did these technologies come from?
- What is the range of our technologies?
- What categories do our technologies fit into?
- What is our standing in our technologies?
- What is the life-cycle position of our technologies?
- What is our performance in acquiring technologies?
- What is our performance in exploiting technologies?
- What is our performance in managing technologies?

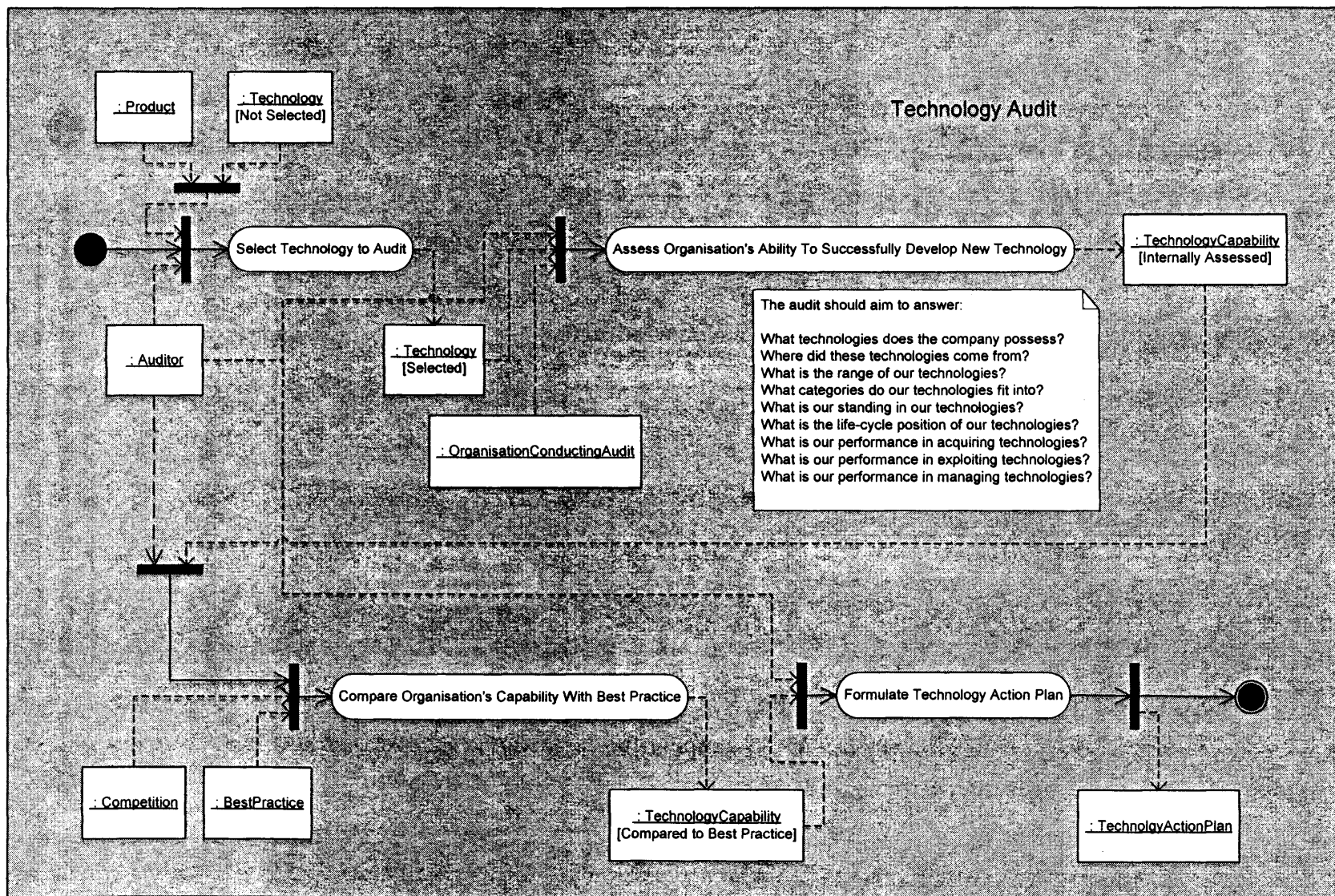


Figure 62 Technology Audit Activity Diagram

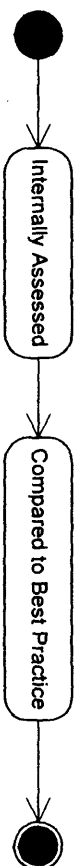
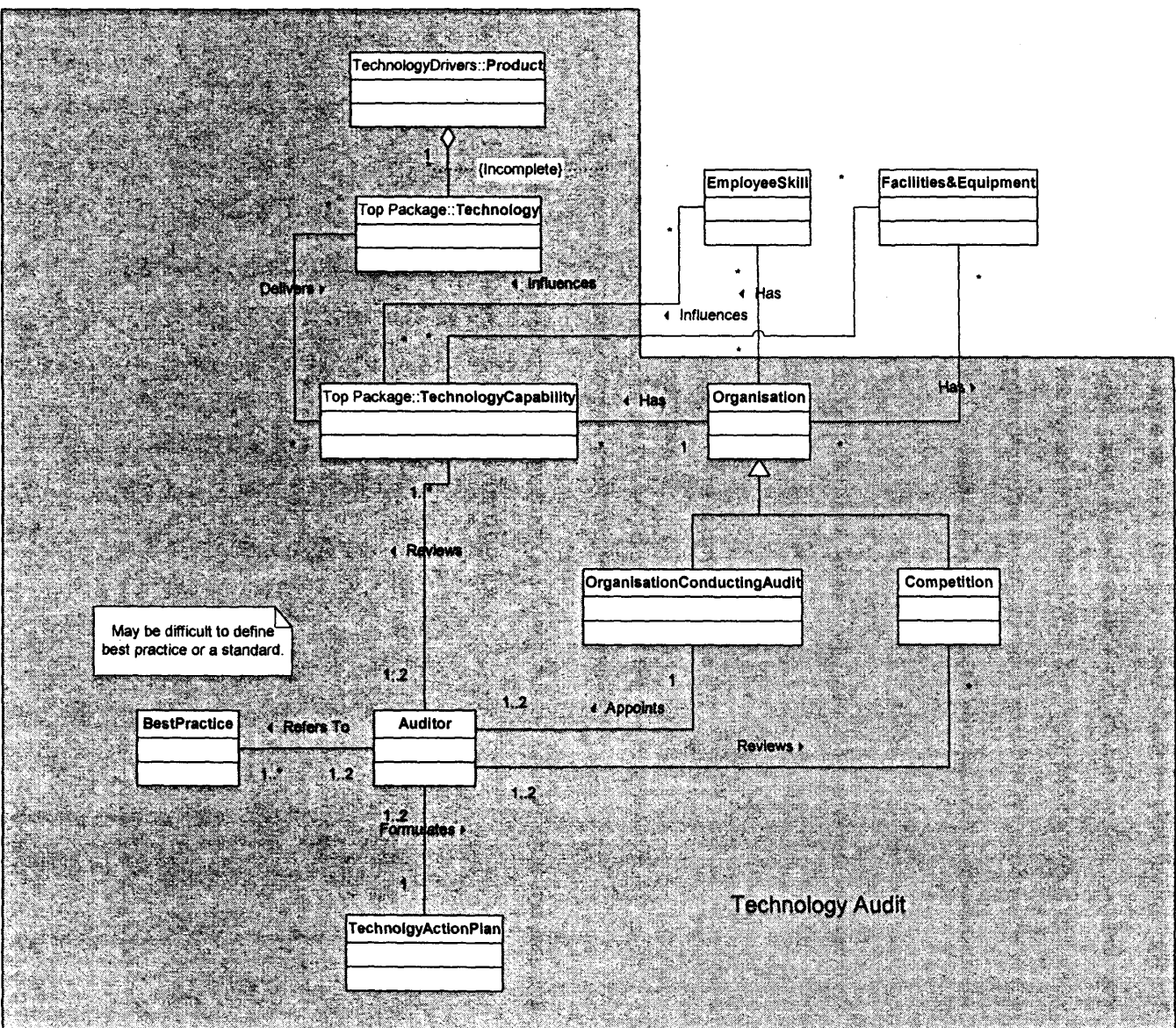


Figure 63 Technology Audit Class Diagram

Figure 64 Technology Capability State Chart Diagram

When using the technology audit process, there is a limitation, in that it can only tell you how good you are at technologies either already in the organisation or new technologies that are similar to ones already in the business (RP38). What the audit will expose is that there is a risk in a new technology being developed in an organisation that has no experience in the technology and that the risk will need to be carefully managed or alternatively outsourced.

5.2.2.5 Review Competitor Capability

Competitors can be a source of new ideas (issue 27). Information about competitors can be sourced via a number of channels (Kotler, 1994, p238):

- From competitors' customers and suppliers (issue 69).
- From competitors' employees.
- From published materials and public documents (eg the Patent Office).
- By observing competitors or analysing physical evidence.

This information regarding the competition's activity can be collated and fed into the Technology Forecast, see Figure 65 for activity diagram.

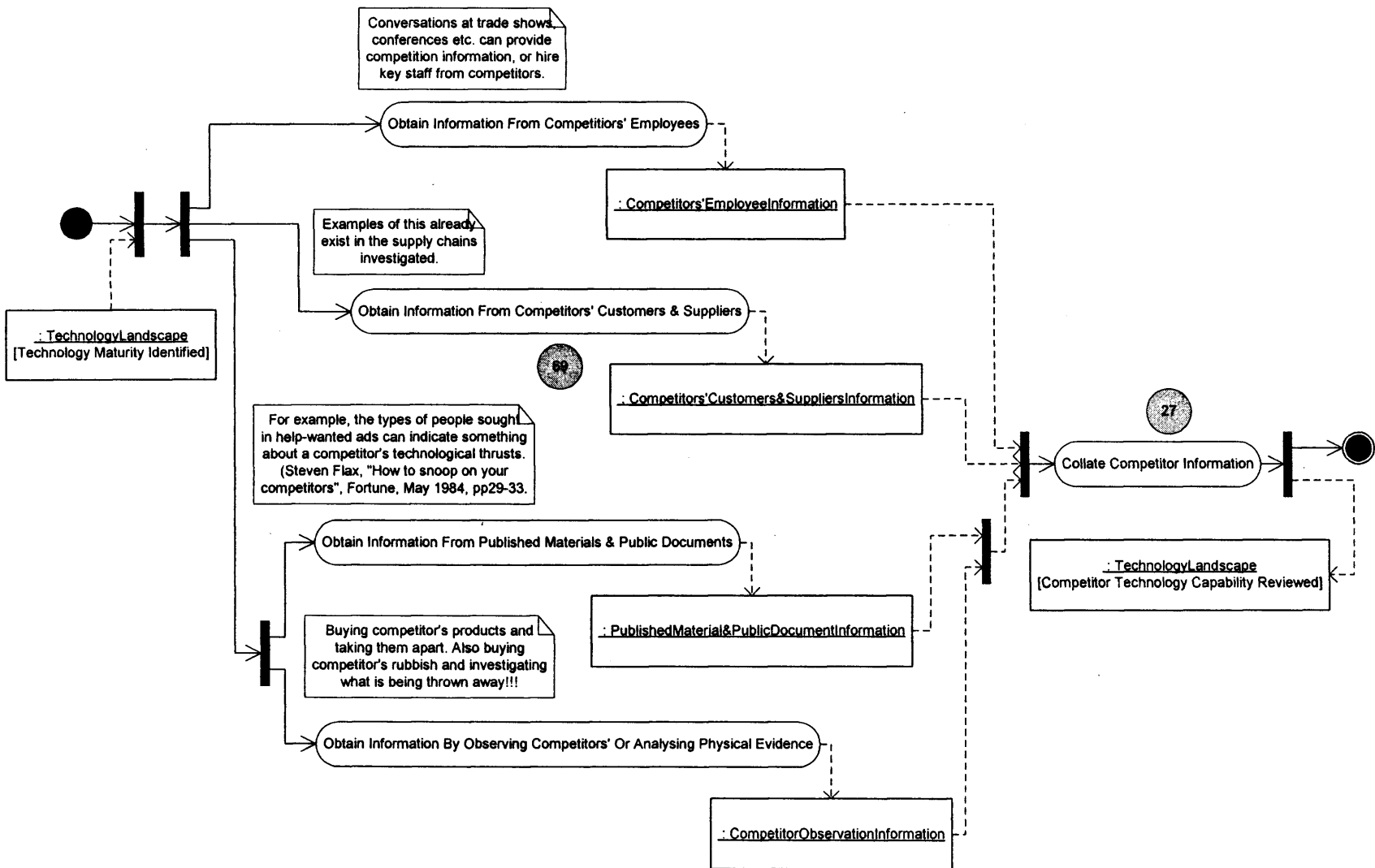


Figure 65 Review Competitor Capability Activity Diagram

5.2.2.6 Review Sources of Technology Capability

The review of the sources of technology capability uses Technology Monitoring, discussed in chapter 2 and modelled in chapter 4, as a mechanism for technology awareness (RP44). The process starts by identifying what type of information is required. The sources of this information are then identified and the data is systematically gathered and processed, see Figure 66 for activity diagram and Figure 67 and Figure 68 for the associated class and state chart diagrams.

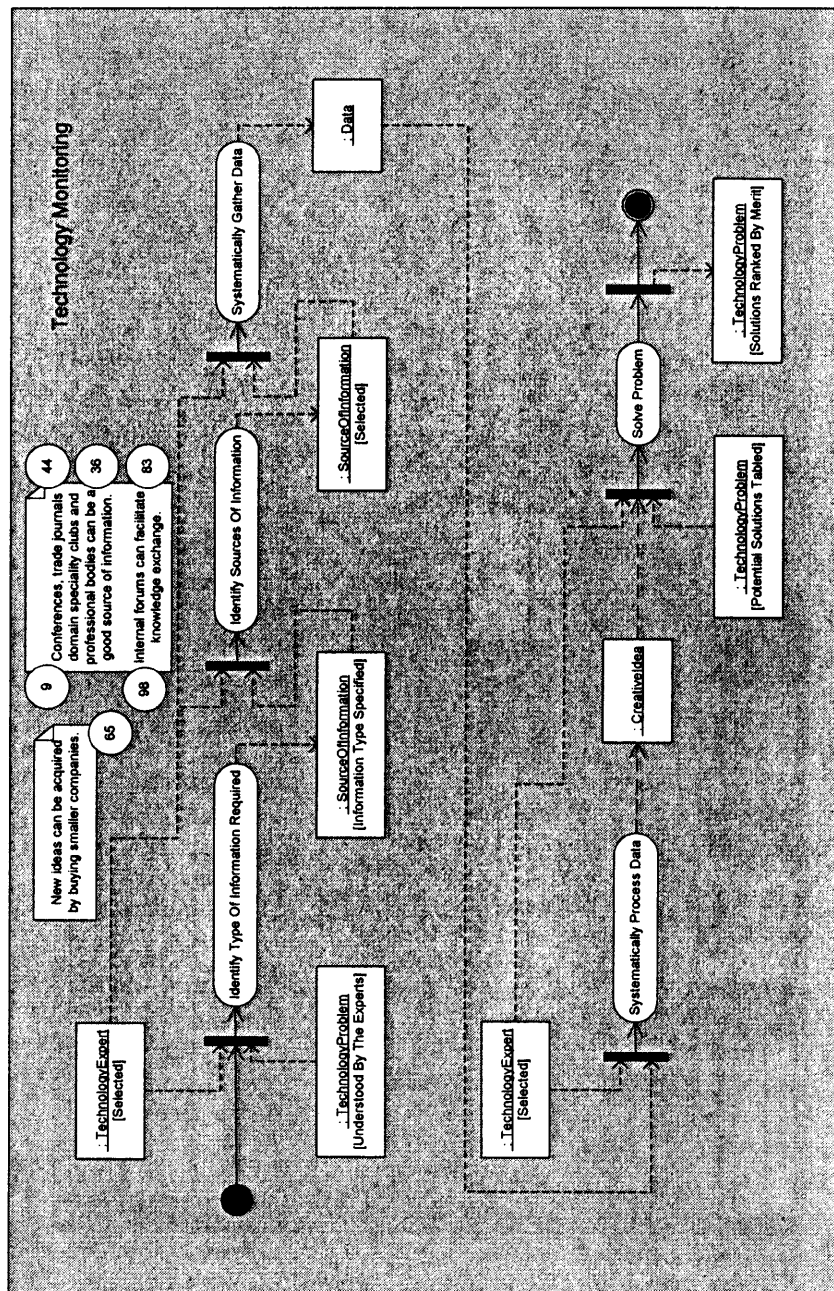


Figure 66 Review Sources Of Capability Activity Diagram

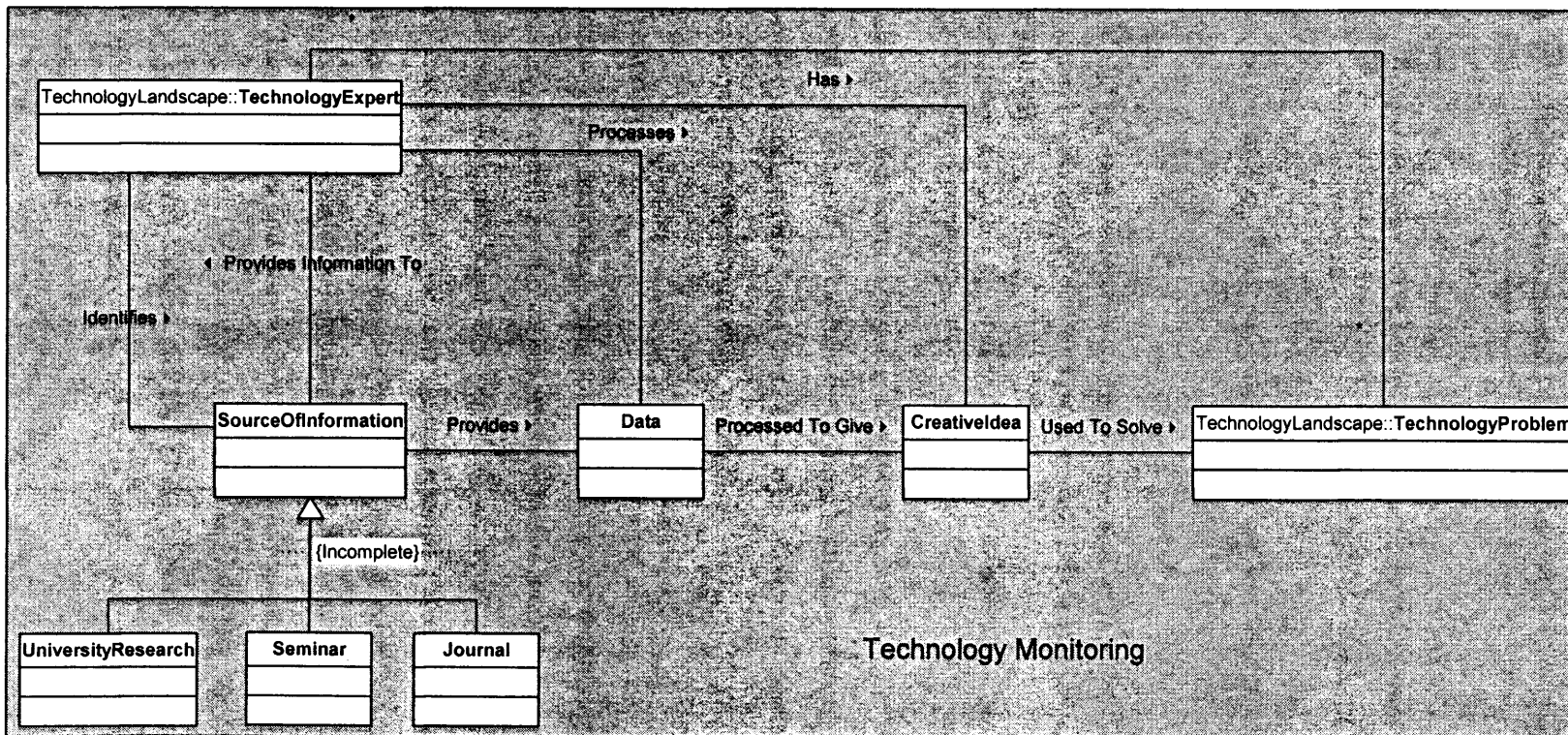


Figure 67 Sources Of Technology Capability Class Diagram

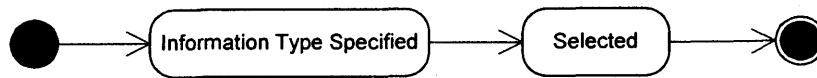


Figure 68 Sources Of Information State Chart Diagram

The sources of technology capability and forums for knowledge exchange include (issue 9, 44, 83, 98):

- Internal and external conferences, symposiums, and workshops.
- Professional bodies and associations, eg the IEE, IMechE, PERA, Sira, etc.
- Trade journals.
- Domain speciality clubs, eg Society of British Aerospace Companies (SBAC), Intersect Faraday Partnership, etc.

An organisation may also acquire new ideas by merging with another organisation that has the capability required (issue 65). This may be by large companies buying smaller ones or by academic institutions amalgamating together. This type of strategy needs to be carefully thought through as it can prove to be high risk.

5.2.3 Produce Technology Plan

The production of the technology plan involves taking the technology landscape and the technology drivers generated by the earlier parts of this technology lifecycle model and exploring different technology outcomes, see Figure 69 for activity diagram and Figure 70 and Figure 71 for the associated class and state chart diagrams. This exploration of outcomes uses scenarios and game theory to investigate different options based on how technology develops, what the competition may be doing and “what if” scenarios for possible future situations (RP22). The scenarios and games identify the requirements for the organisation to compete in the future (issue 73). They are also important in evaluating the cost/benefit side of the research and development decision (RP29). These options are then plotted onto a roadmap (issue 99). By limiting each roadmap to a single scenario, it will reduce the complexity of the roadmap (issue 39).

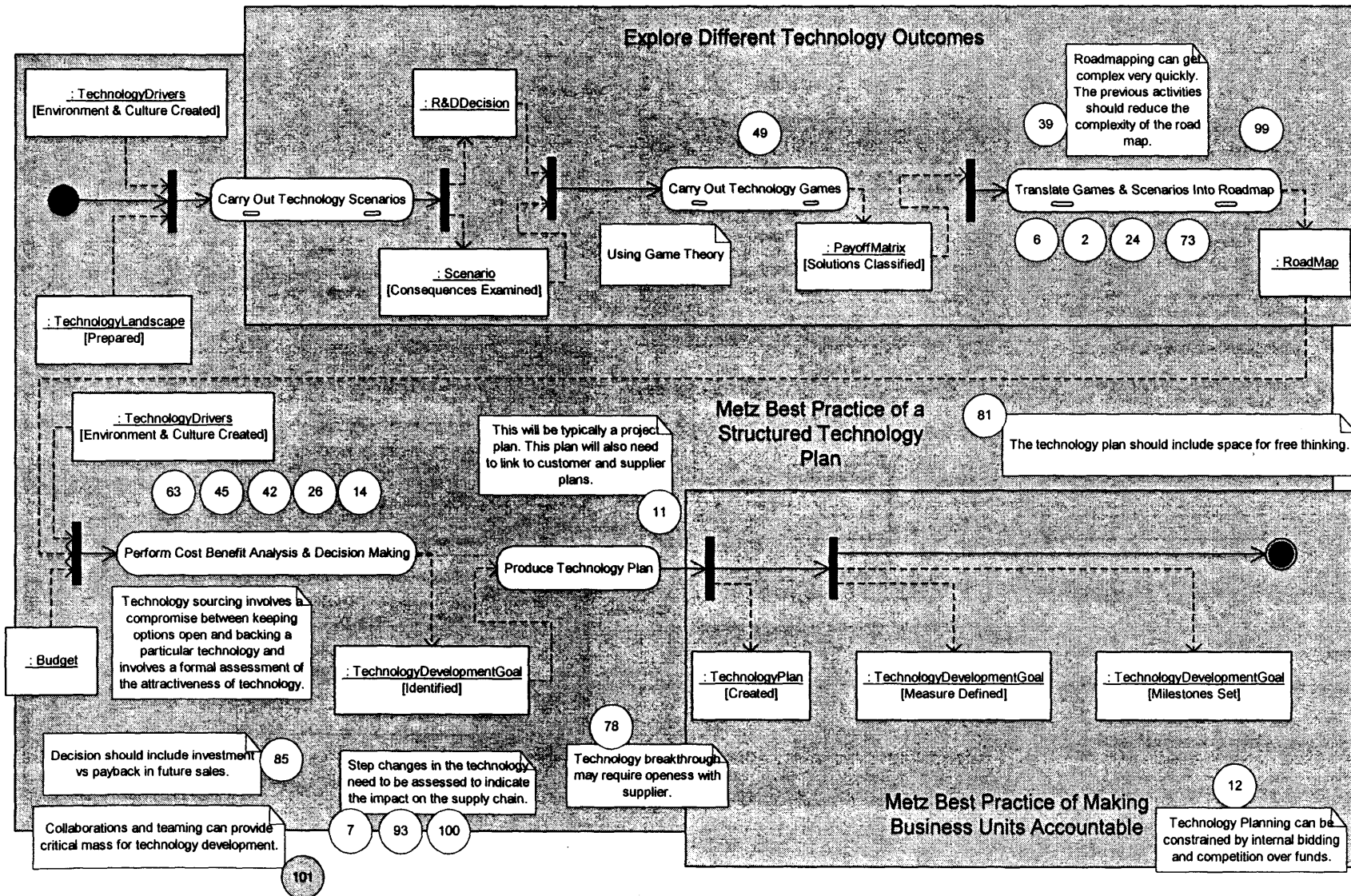
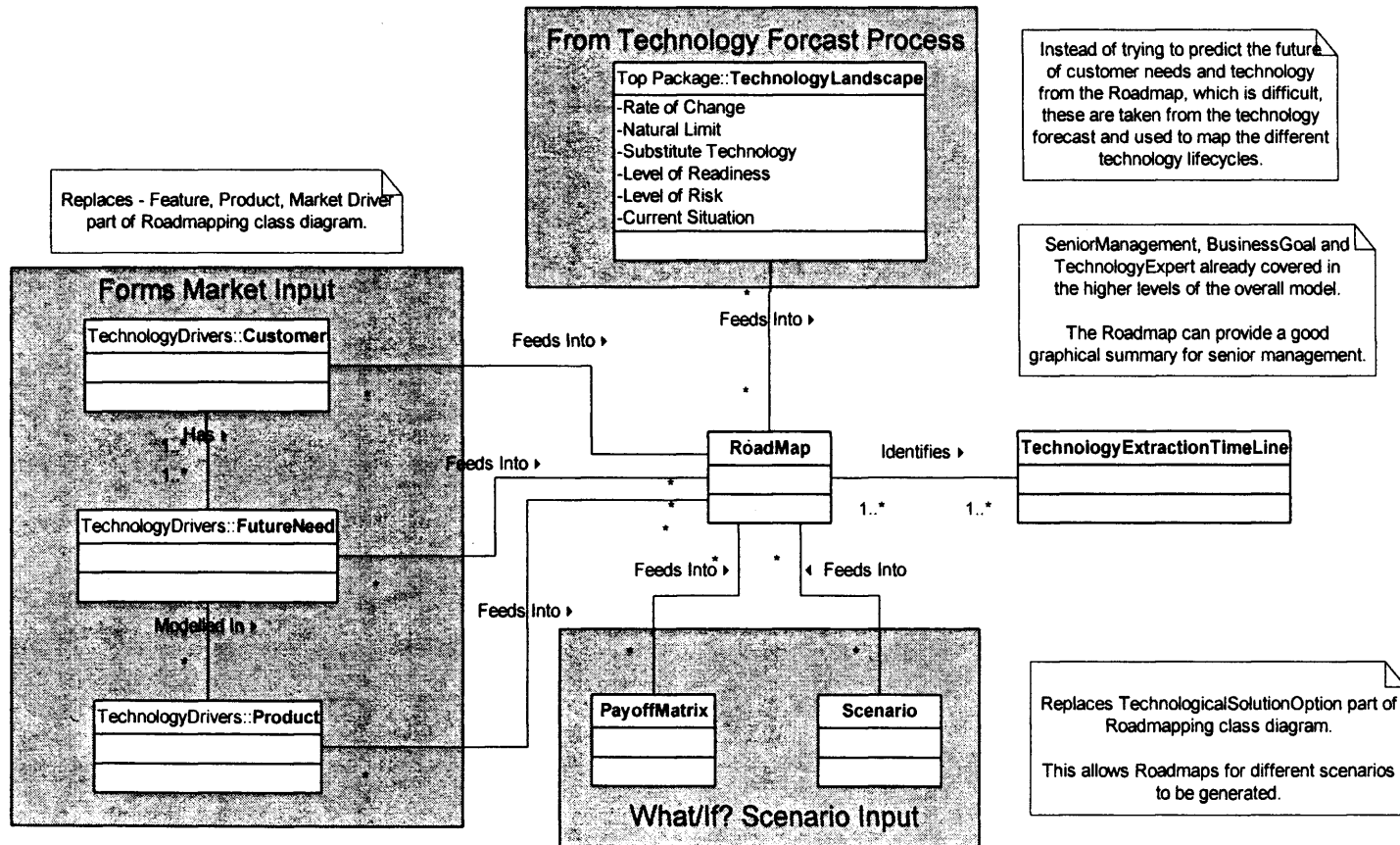


Figure 69 Produce Technology Plan Activity Diagram



Figure 71 Technology Goal State Chart Diagram

Figure 70 Technology Roadmap Class Diagram



The roadmaps for each option can be assessed against the original set of technology drivers for cost/benefit trade offs and technology planning decisions. These decisions are affected by the nature and size of organisation making the decision (issue 77). Technology trade offs involve a compromise between keeping options open and backing a particular technology and requires a formal assessment of the attractiveness of each technology (issue 14) (RP28). These trade offs are used as the basis for technology decision making, i.e. “where do I invest my money to get the *biggest bang for the buck?*” (issue 63), who can I team/collaborate with to provide a critical mass for technology development (issue 101)?

Trade off decisions should also include technology investment versus payback models (e.g. in future sales) (issue 85). There are many tools and decision support frameworks that can be used to aid the cost benefit trade offs for technology research and development strategies, for example the Simulation With Optimisation for Research and Development (SWORD) tool developed by Gormley et al (2004). An example of this type of decision making tool can be found in chapter 6 (section 6.2.1.4.4) of this thesis.

The output of the decision making process is used to produce a structured technology plan (one of Metz (1996) Best Practices) and includes research and development funding requirements (issue 42). The use of the roadmaps aids the decision making process as they provide a visual representation of what can be achieved by when and provide a graphical summary for management (RP53). These roadmaps can also be easily translated into a GANTT chart or network (PERT) diagram.

The planning period needs to be determined by the organisation implementing this lifecycle model. However it should be more longer term than traditional product planning lifecycles to address where technologies of interest may be going and what is likely to replace them. The technology planning lifecycle is there to give an organisation a ‘heads up’ of what may be coming on the horizon and should therefore not be too short term (issue 24).

The technology planning period is constrained by the organisation’s budgetary cycles (issue 45) and these should be identified from the business objectives that are used to determine the technology drivers. The technology plan is also constrained by the organisation’s internal bidding process for resources (issue 12). Again this should be

identified during the development of the technology drivers and addressed in the technology decision making process as part of generating the plan.

The technology plan needs to not only address links to customers, but also needs to include the link between the organisation and its supply chain (issue 11). The customer aspects are covered by the business and technology drivers (which includes a customer needs review that includes timescales). Any technology that is outsourced requires the technology plan and decision making process to be linked to the supplier, as they may contribute to the assessment of the attractiveness of the technology (issue 26). How this is managed depends on the organisation's ability to influence its suppliers (one of Porter's (1979) Five Forces).

As part of assessing the link to customers and suppliers, the technology plan needs to identify if technology demonstrators are required in order to prove concepts, capture or refine requirements and to gain end-user buy-in to the technology.

The supply chain also needs to be included in the technology planning process as step changes in either new technology or the use of particular technology can have a major impact on the whole supply chain (issues 7, 93 & 100). In addition, if an organisation is trying to achieve breakthrough technology, it will require openness with its suppliers in order to achieve this (issue 78). Lack of openness may catch the suppliers out or they may go off on a different development tangent.

The technology plan will include specified milestones (issues 2 & 6) and measures for the technology development goals of the organisation. These can be used to hold business units accountable for their contribution to the technology plan (another of Metz's (1996) Five Best Practices). The technology plan should also include space for free thinking (issue 81) and hence it is recommended that technology development is carried out as a separate stream to product development. The technology and product development streams can then be linked by technology insertion points (issue 4), where the technology has become mature enough (readiness) to be incorporated into a product without large levels of risk to both the technology and product developments (issue 8). This approach is also supported by Schulz et al (2000).

5.2.3.1 Carry Out Technology Scenarios

This part of the production of the technology plan uses the scenario technique described in chapter 2 and modelled in chapter 4. The scenario uses a framework and a series of events and decisions are defined see Figure 72 for the scenario activity diagram and Figure 73 to Figure 75 for the associated class and state chart diagrams. The various scenarios are then explored along with their consequences. The output of this process is used to produce the roadmaps which feed into the decision making activity to underpin the decisions made. It is useful for the scenarios to be present in the mind of the decision maker (RP27) as they are important in evaluating the cost/benefit side of research and development investment decisions (RP29).

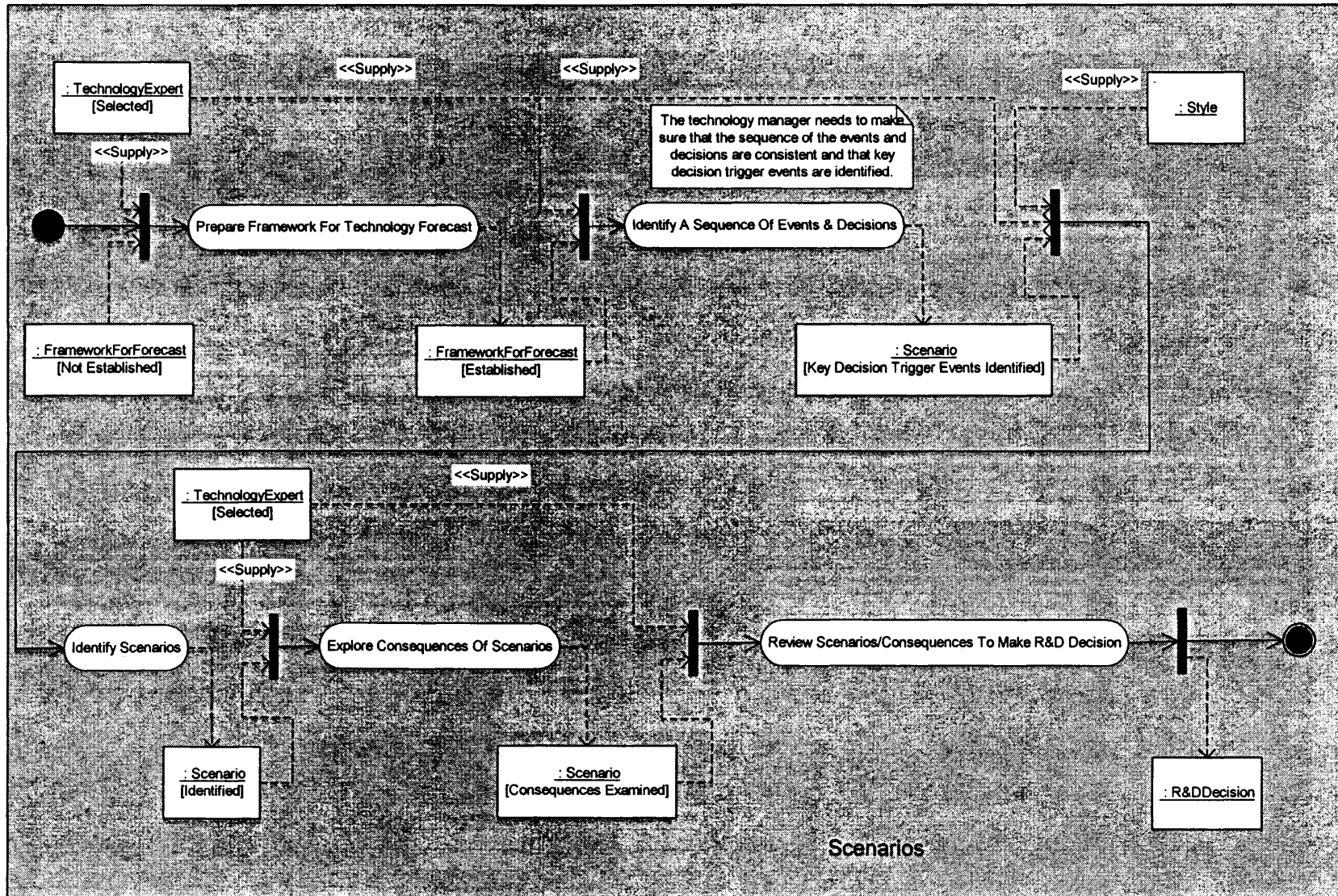


Figure 72 Scenario Activity Diagram

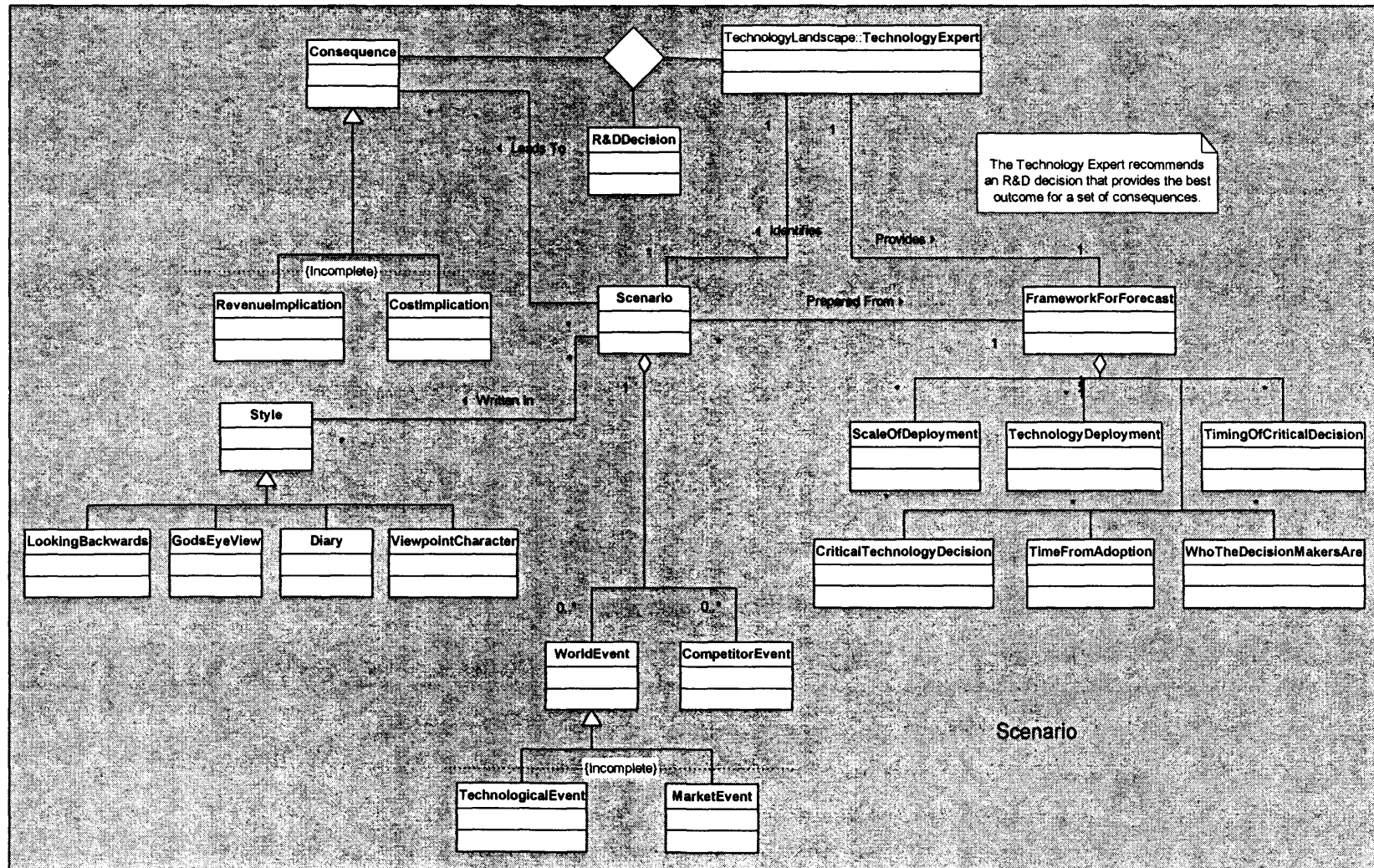


Figure 73 Scenario Class Diagram

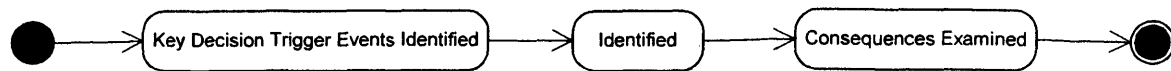


Figure 74 Scenario State Chart Diagram

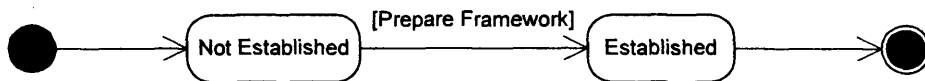


Figure 75 Framework State Chart Diagram

5.2.3.2 Carry Out Technology Games

Game theory technique, described in chapter 2 and modelled in chapter 4, is useful in support of the scenario technique, see Figure 76 for activity diagram and Figure 77 to Figure 79 for associated class and state chart diagrams. The first step in the game theory process is to identify the parameters for the game, see Figure 80 for activity diagram. A pay off matrix is created that enables the classification of solutions, see Figure 81 for activity diagram. The various game scenarios are then explored along with their consequences on the pay off matrix. The game theory technique allows one to explore how one's own best strategy is affected by the actions of competitors (RP22). The output of this process, along with the scenarios, is used to produce the roadmaps which feed into the decision making activity to underpin the decisions made. It is useful for the game theory outputs to be present in the mind of the decision maker as they are important in evaluating the cost/benefit side of research and development investment decisions (RP29).

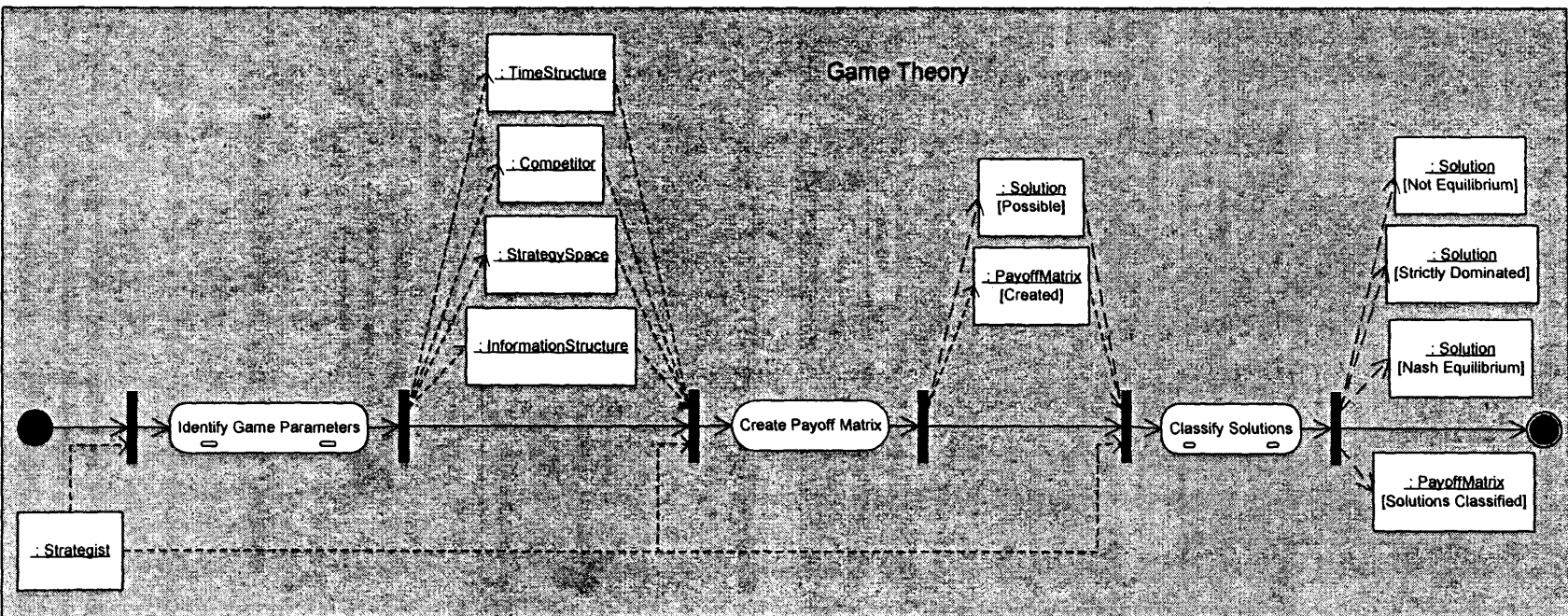


Figure 76 Game Theory Activity Diagram

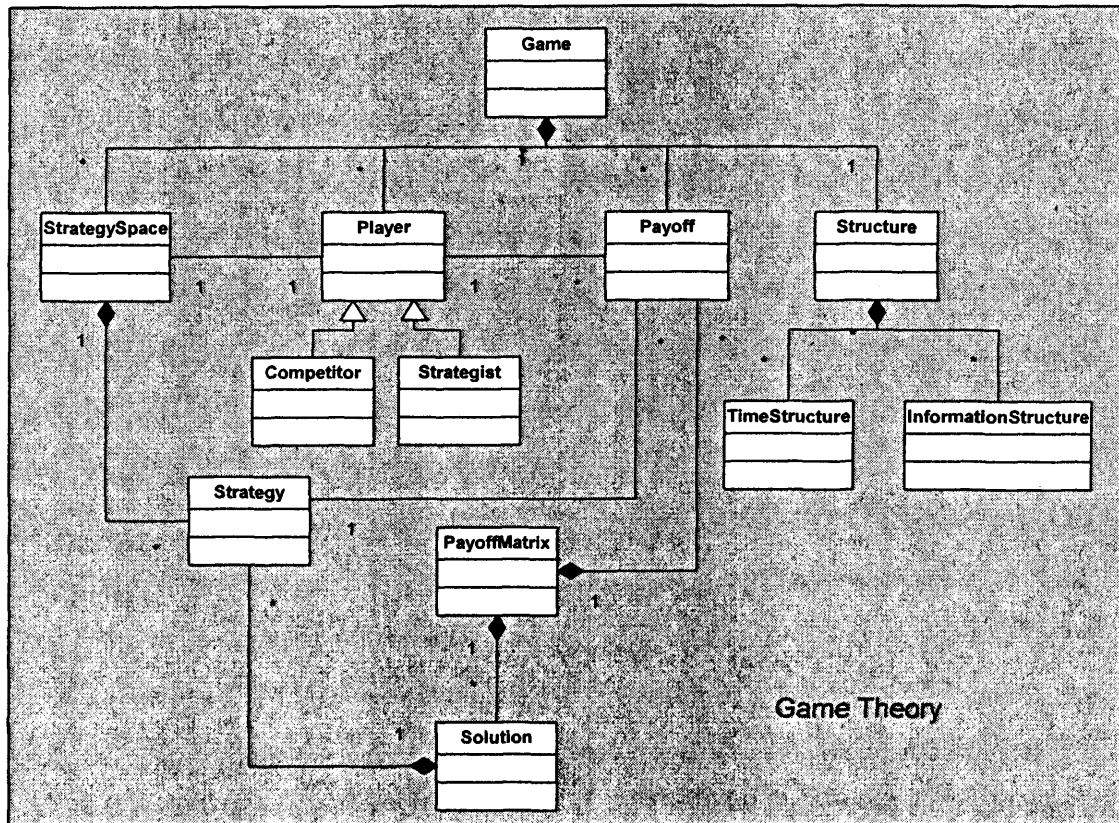


Figure 77 Game Theory Class Diagram

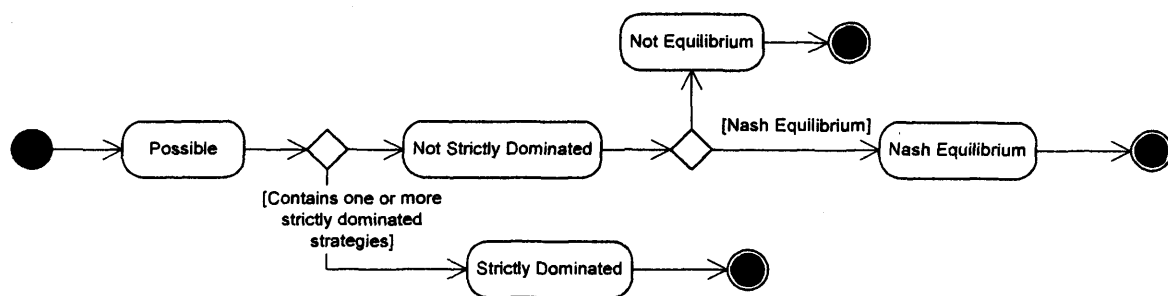


Figure 78 Solution State Chart Diagram

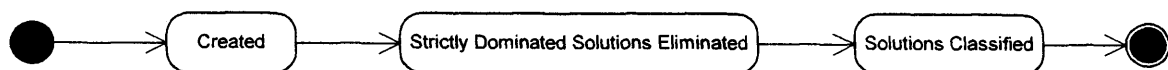


Figure 79 Pay Off Matrix State Chart Diagram

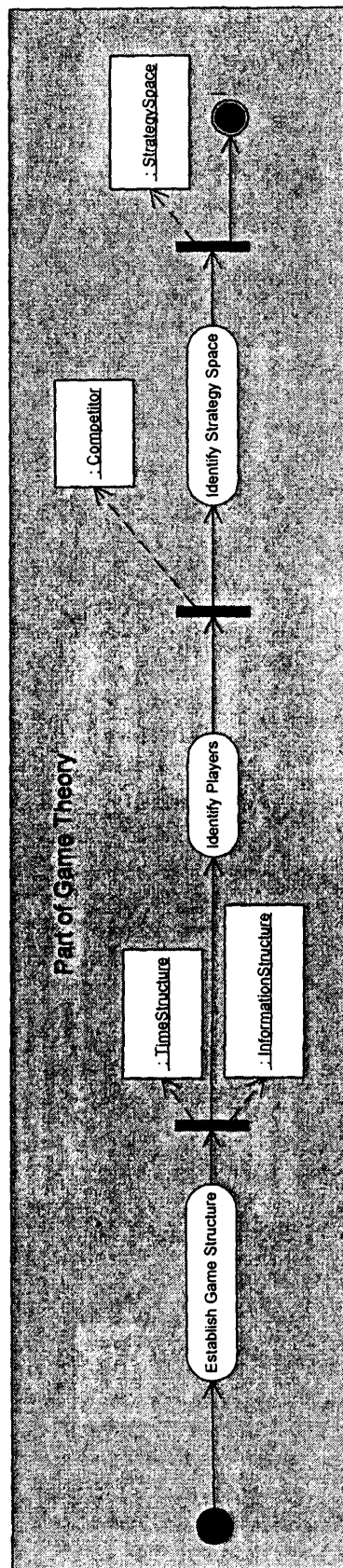


Figure 80 Identify Game Parameters Activity Diagram

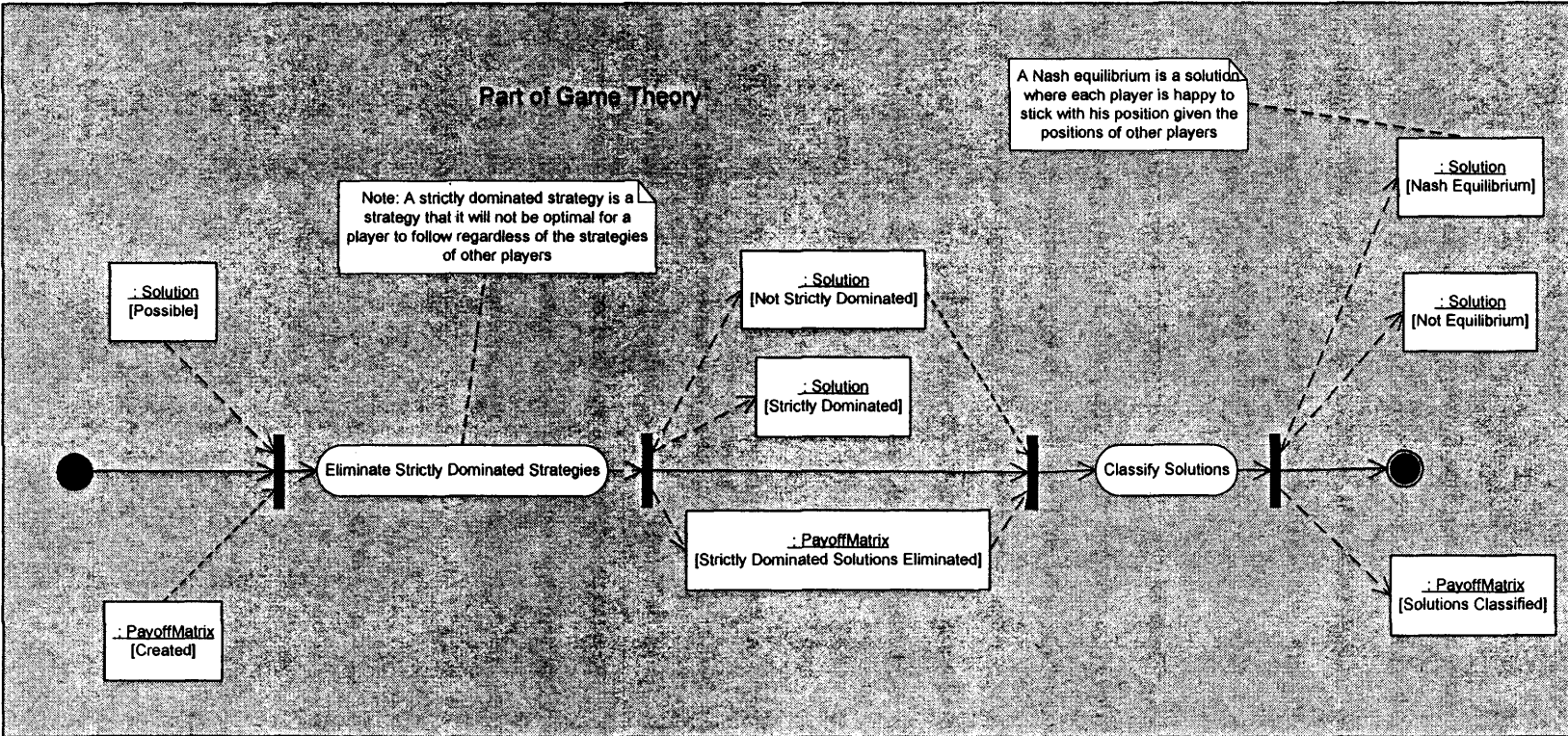


Figure 81 Classify Solution Activity Diagram

5.2.3.3 Translate Games & Scenarios Into Roadmap

The roadmapping in this technology planning and management lifecycle model only uses a part of the technique described in chapter 2 and modelled in chapter 4, see Figure 82 for activity diagram. The rest of the roadmapping process is covered by the earlier stages of this technology planning lifecycle model, as some of the other techniques used are similar (RP52). In addition, the earlier parts of the process address the limitation of roadmapping being able to make technology predictions (RP51).

The essence of this activity is a workshop to chart milestones, products & technology evolutions using information about the customer, their future needs, and the needs of the business, existing and future products and technology. This information is supported by the outcomes from the outputs of the scenario and game theory activities and the technology landscape generated from the technology review. These roadmaps will be used to identify and highlight the different lifecycles that each technology has and how this maps onto the requirements of the organisation (RP50 & 51).

The output of this activity is a series of roadmaps for each technology (RP51) that chart possible options as technology comes and goes (RP50) and includes key milestones and technology insertion points into the product stream (issues 4 & 8). The roadmap also indicates how customer and supplier technology affects the organisation's technology plans. These influences indicate the overlapping areas of technology planning between customer and supplier and should be addressed by customer/supplier involvement in the organisation's technology planning process.

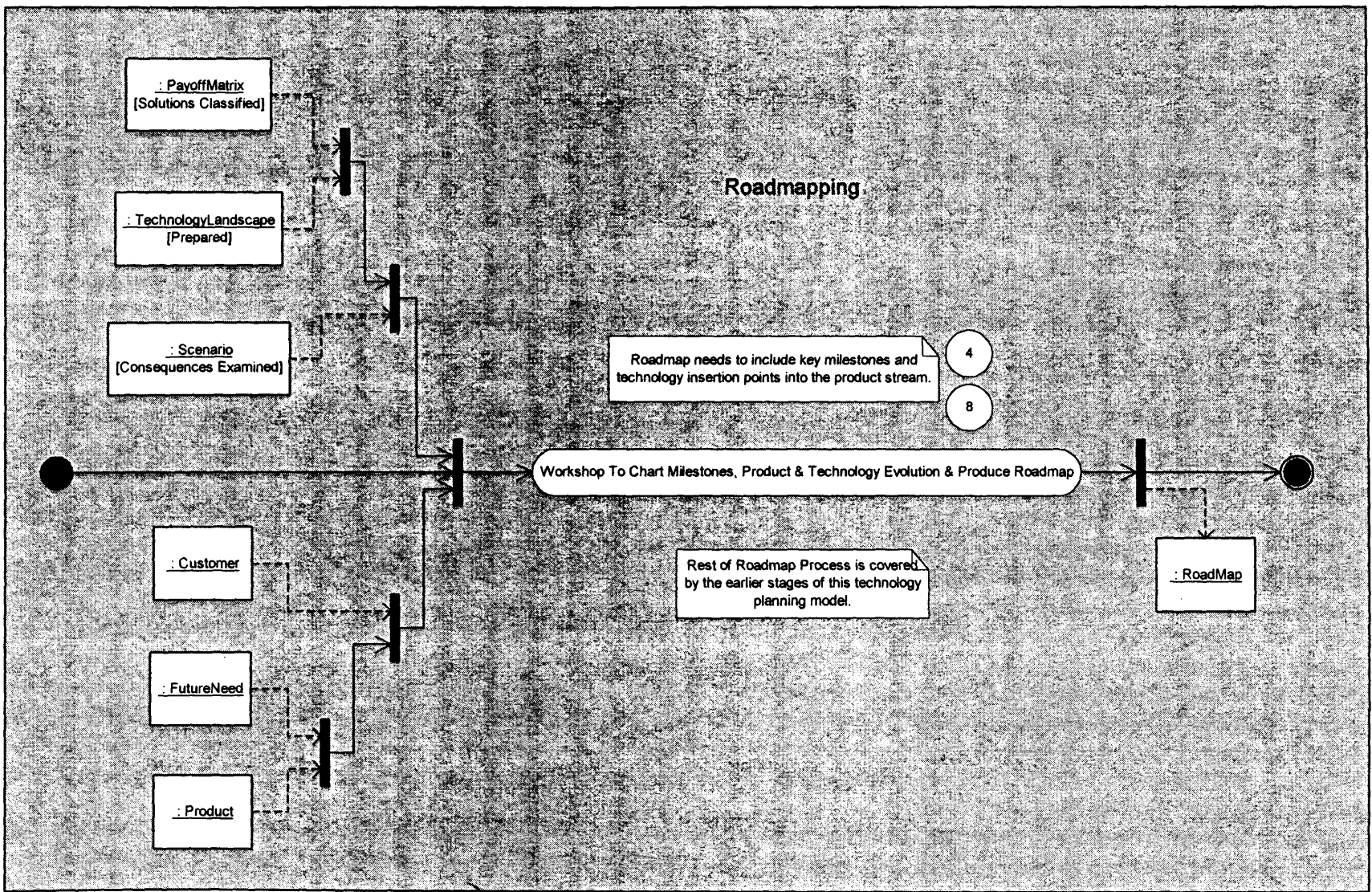


Figure 82 Roadmapping Activity Diagram
207

5.2.4 Implement Technology Plan

The important part of any technology plan is the implementation, as already pointed out by Braun (1998, p55) in that technology planning is only half the story. In this model, see Figure 83 for activity diagram, each technology will follow one of the three parallel implementation paths depending on whether the plan indicates that it is:

- Existing and continues to be exploited.
- Existing and requires disposal.
- Or is new and requires introduction into the organisation (issue 47).

The output of the implementation of each technology activity is an actual performance which is used to monitor the implementation process. This monitoring is discussed later on in this chapter.

Although each technology has its own parallel path, substitute technologies require their introduction to be linked to the disposal of the technology they replace in order to ensure there are no gaps in the implementation between the two technologies.

In parallel with the multiple technology implementation paths, are the management of the other organisation's activities, for example production and product development. However, this needs to be co-ordinated with the technology development implementation to ensure organisational activities that affect technology development are fed into the technology planning process and that technology development issues that affect the organisation's other activities are fed into them. To carry out this co-ordination there is an additional activity called Harmonise Technology Management which manages the data/information and control between the organisation's other functions and the technology development. This collaborative approach is recommended by Metz (1996) best practice of fostering involvement between departments (issues 5 and 43).

In addition to the Harmonise Technology Management activity there are also activities to harmonise both customer and supplier technology plans. These activities ensure that the organisation's implementation of their technology plan is still aligned to their customers' and suppliers' plans.

Should be collaborative Technology Projects as per Metz Best Practice of Fostering Involvement Between Departments

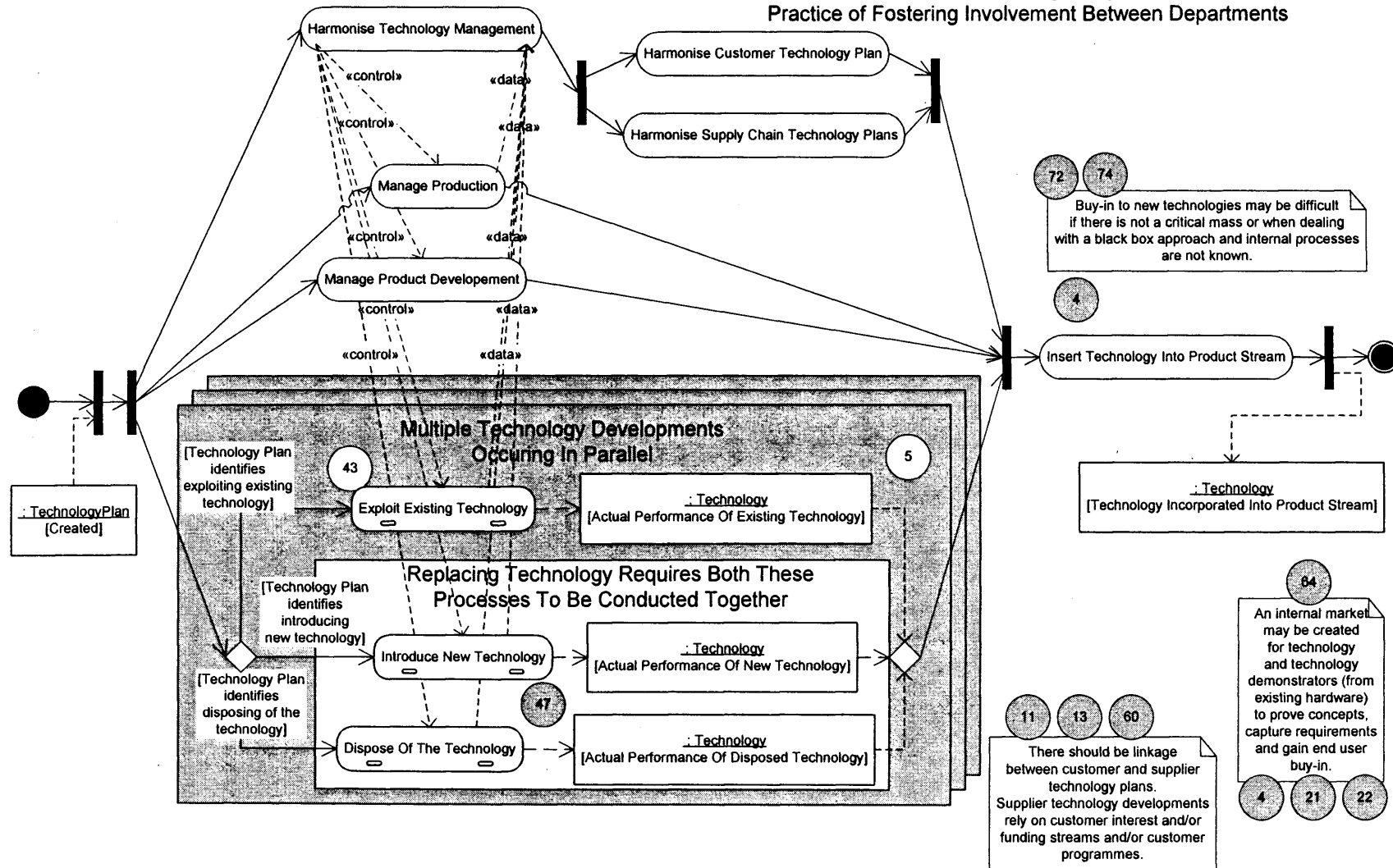


Figure 83 Implement Technology Plan Activity Diagram

The final part of the technology implementation process is the insertion of the technology into the product stream. This insertion may be 'easier said than done' as buy-in to new technologies may be difficult if there is not a critical mass or when dealing with a black box approach and internal processes are not known (issues 4, 72 and 74). The use of technology demonstrators (can be configured from existing hardware (issue 64)) can help with overcoming the barriers of technology buy-in (issues 21 and 22). The use of technology demonstrators also requires good expectation management to avoid disappointment and re-enforcing of scepticism. Understanding the classification of product development can help in this expectation management (Cowper et al, 2004).

5.2.4.1 Exploit Existing Technology

Using the technology plan and the information about the organisation's current capability in an existing technology, the first part of the exploit existing technology process is to review the current level of investment, see Figure 84 for activity diagram and Figure 85 to Figure 88 for supporting state chart diagrams. The current level of investment is compared to the level stated in the technology plan and can be adjusted accordingly (increased, decreased or remain the same).

The organisational structure is then reviewed to determine if it is still suitable for developing the technology (one of Metz (1996) Best Practices). If the current structure is not suitable to develop the technology, then it can be reorganised to make it suitable. This can be non-trivial and takes management and employee commitment to achieve a successful reorganisation.

The last two parts of the process includes reviewing the skills of the employees developing the technology and the facilities and equipment. Both of these can be conducted concurrently and this is at the heart of the organisation's technology capability. In both cases where there are deficiencies there is a choice between developing existing internal skills/facilities and equipment or buying it in. This latter part of the process requires senior management commitment to provide the necessary resources.

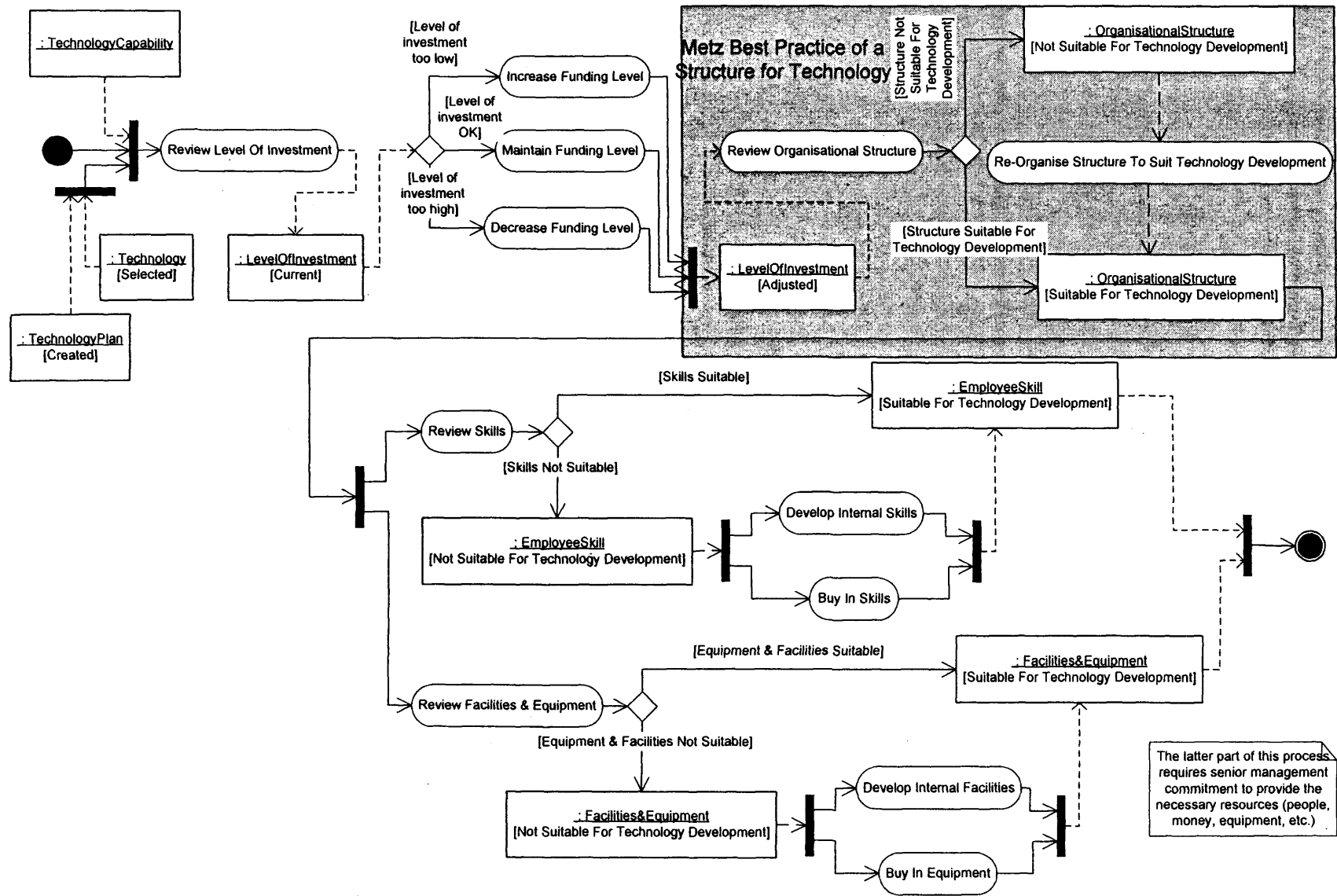


Figure 84 Exploit Existing Technology Activity Diagram

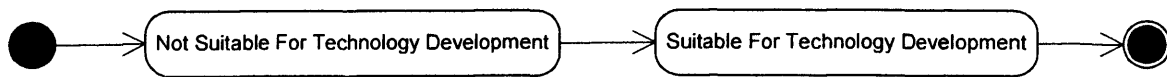


Figure 85 Organisational Structure State Chart Diagram

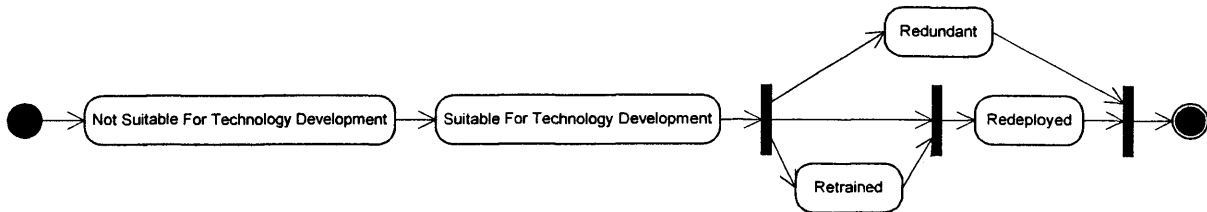


Figure 86 Employee Skill State Chart Diagram

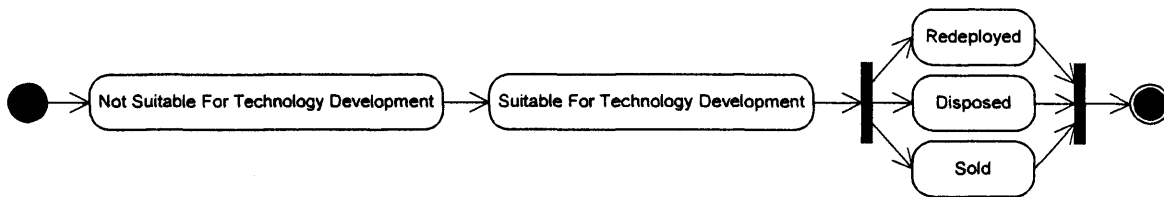


Figure 87 Facilities And Equipment State Chart Diagram



Figure 88 Level Of Investment State Chart Diagram

5.2.4.2 Introduce New Technology

The introduction of new technology, see Figure 89 for activity diagram, is similar to the exploiting of existing technology. The organisation first needs to review its structure's suitability for developing the technology and then review its skills, facilities and equipment. In this case it is more likely that the structure, skills, facilities and equipment will require modification to embrace the new technology.

The introduction of new technology, if replacing an existing technology, needs to be closely linked with the disposal of that technology. This is to ensure that the organisation does not get caught between the removal of the technology and the new technology being mature enough to be inserted into the product/service stream.

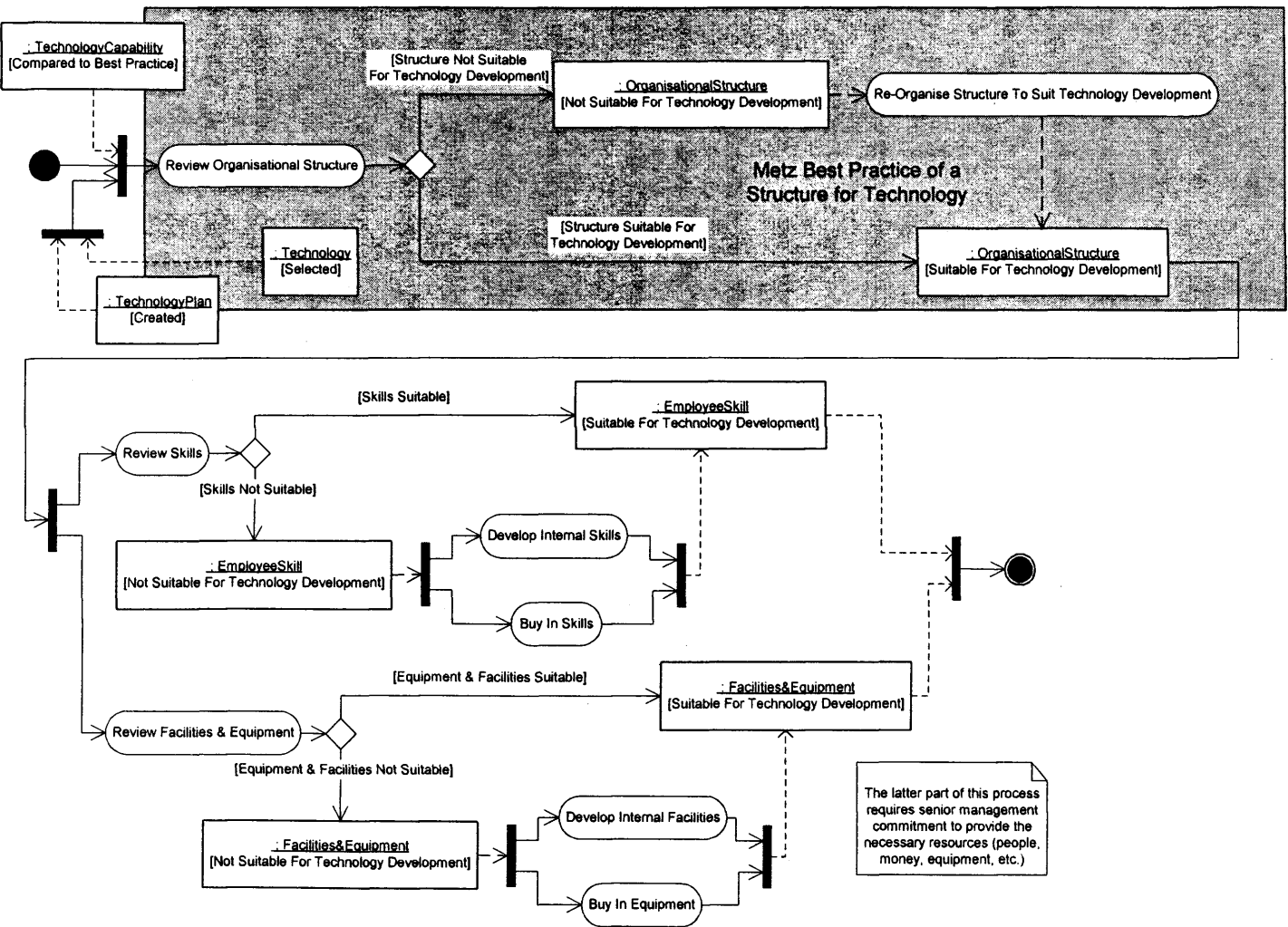


Figure 89 Introduce New Technology Activity Diagram

5.2.4.3 Dispose Of The Technology

Disposing of the technology involves deciding if the technology is to be sold on to another organisation or if it is simply being phased out of the organisation. Selling the technology on is fairly common practice in cases where there may be some financial life left in the technology (cash cow) but does not fit with an organisation's business objectives. For example, BAE Systems Avionics business sold the design and maintenance rights of their older air data products to Meggitt Avionics. This range augments Meggitt Avionics product range and therefore fits with the organisation's objectives and at the same time frees up BAE Systems to concentrate on developing their new range of flight control products. The sell or phase out decision will usually be made as part of the 'produce technology plan phase' of this lifecycle model.

If the technology is to be sold, suitable buyers need to be identified, see Figure 90 for disposing of the technology activity diagram and Figure 91 for technology buyer state chart. Once a suitable buyer has been identified the rest of the process is simply a business transaction; agree sale, negotiate terms, due diligence and the transfer of capability and resources. The timeline for the sale will be subject to the negotiations of the sale. This process is simply based on the author's own experience of transferring a technology out of a business when Ultra Electronics decided to sell its HelituneTM product range to Beran Ltd.

If the technology is to be phased out, the first part of the process is to establish a timeline for extracting the technology. The process then deals with both employees and equipment in parallel. Employees will be either redeployed within the organisation, redeployed after training or made redundant. Equipment will be redeployed within the organisation, sold or thrown away (written off). Depending on the type of equipment, the disposal may incur an additional cost to the organisation, especially under recent European environmental legislation (e.g. Directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment).

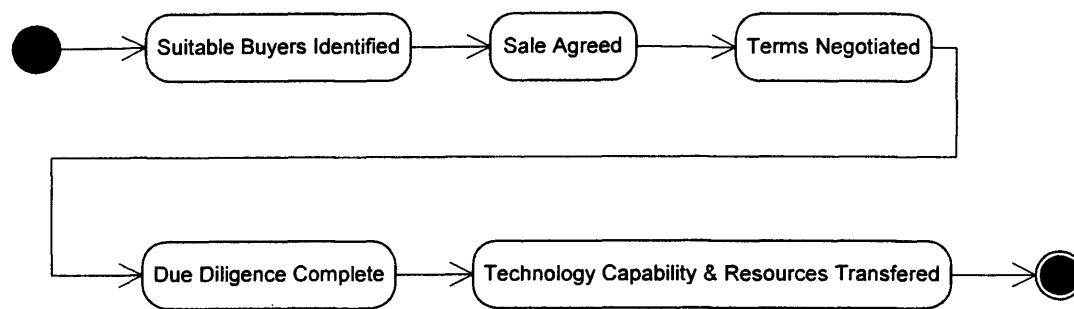


Figure 91 Technology Buyer State Chart Diagram

5.2.5 Technology Implementation Monitoring

Technology implementation monitoring consists of carrying out benchmarking, technology audits and reviews of competitors' technology capability during the implementation of the technology plan, see Figure 92 for the activity diagram. Conducting a technology audit and reviewing competitors' technology capability have already been described in sections 5.2.2.4 and 5.2.2.5 respectively. Details of technology benchmarking are provided later.

The Technology Implementation Monitoring part of the model provides a feedback path to ensure the implementation of technology development is conforming to the technology plan. Any deviations should result in either an amendment to the implementation or an amendment to the plan. The implementation monitoring can occur at any point during the implementation process and may be a continuous activity.

The aim of these activities is to gather data on actual performance. The last part of the technology implementation monitoring process is to compare actual performance against planned performance. This provides a way of holding business units accountable, one of Metz (1996) Best Practices.

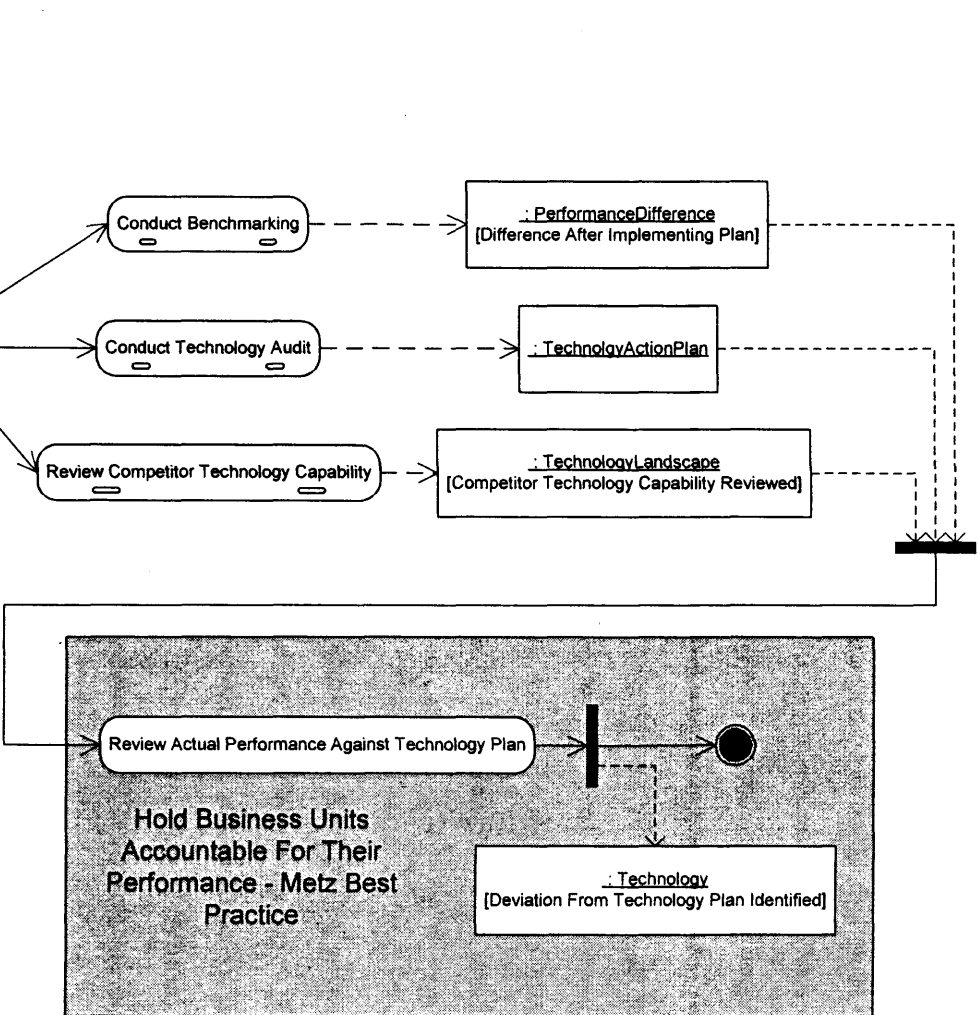


Figure 92 Technology Implementation Monitoring Activity Diagram

5.2.5.1 Conduct Technology Benchmarking

The Technology Benchmark process is based on the benchmarking model described in section 4.18 of chapter 4, see Figure 93 for activity diagram and Figure 94 to Figure 96 for associated class and state chart diagrams. The process begins by identifying Metrics (e.g. Performance, Value, and Number of Patents) and comparative organisations to benchmark against. The metrics need to be identified up front to define what is being compared (RP42). Values for these metrics need to be obtained prior to implementing the technology plan in order to obtain a before and after picture (RP41). The metrics used to benchmark the organisation should at least contain the same measures used to assess the technology's competitive impact and position (RP39). These measures should also provide a link to the organisation's business requirements, e.g. core competencies, value, control, etc. (RP40)

The organisation then needs to establish a Data Collection Method to answer the questions; "how good is the technology?" and "how good am I at the technology?" (RP43). The results of the data collecting are then analysed to understand the performance difference and a performance level forecast and benchmarking report are then produced. The organisation defines functional goals and develops and implements an action plan to develop weak areas.

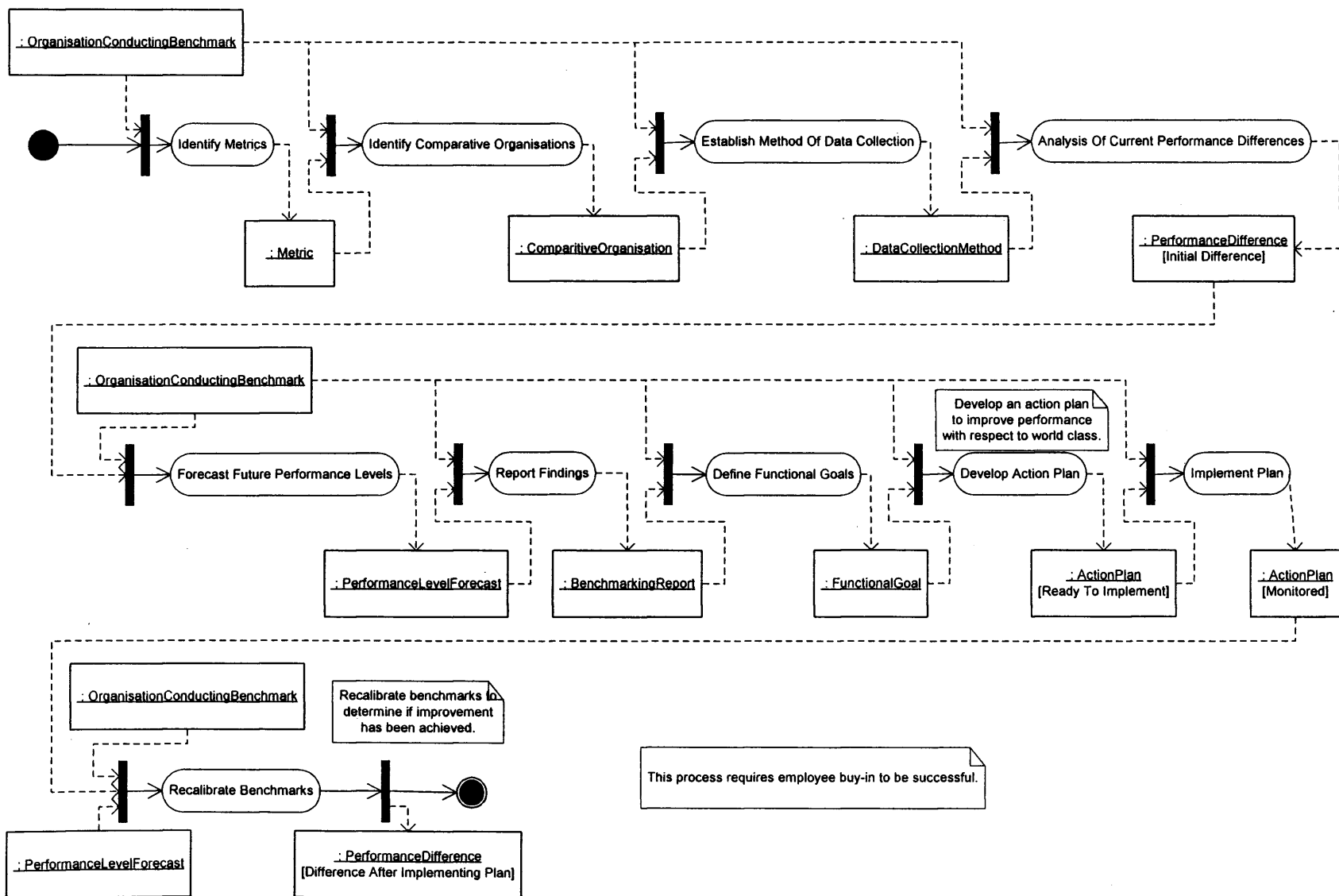


Figure 93 Benchmarking Activity Diagram

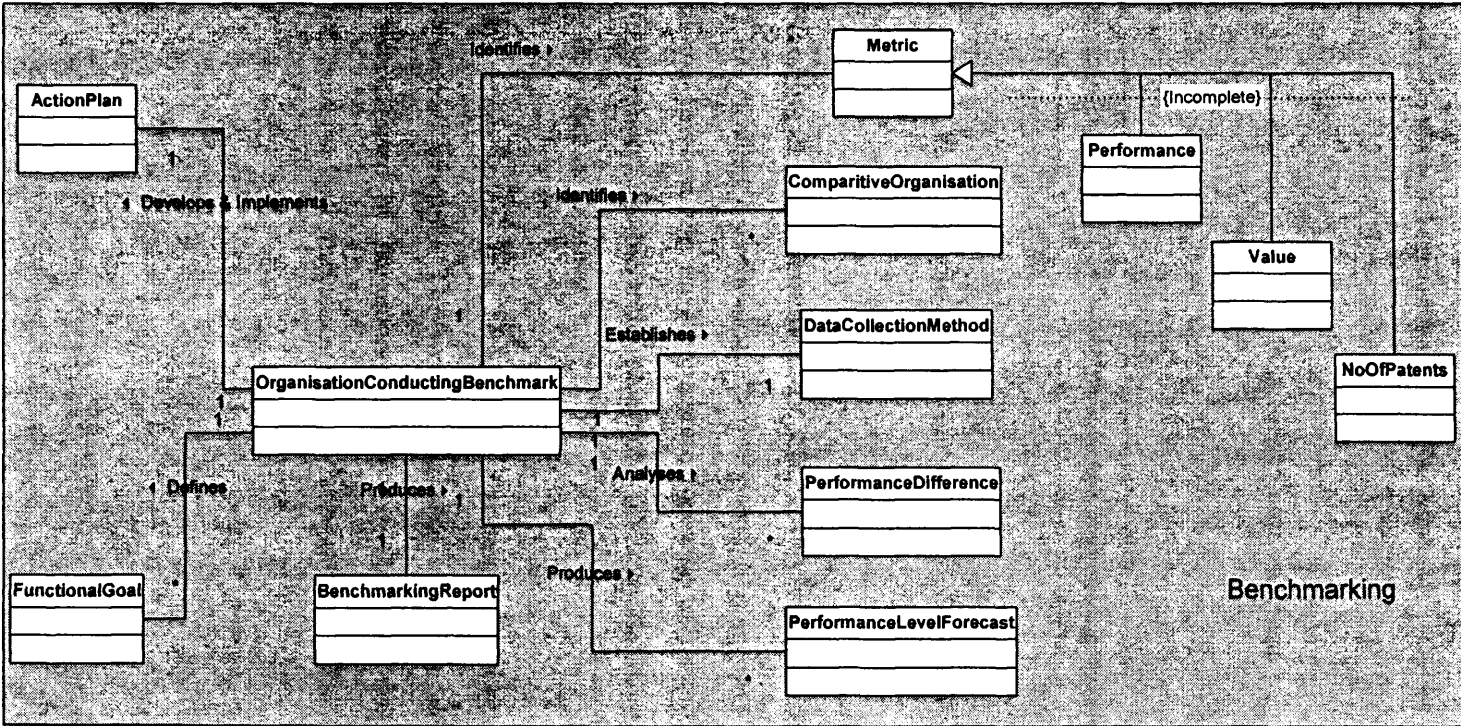


Figure 94 Benchmarking Class Diagram

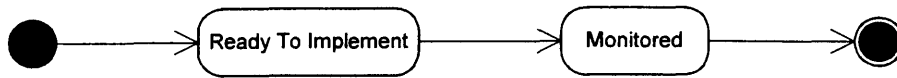


Figure 95 Action Plan State Chart Diagram

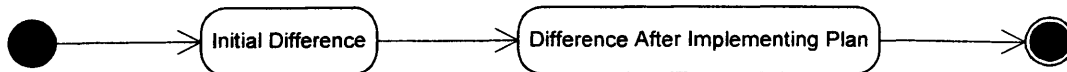


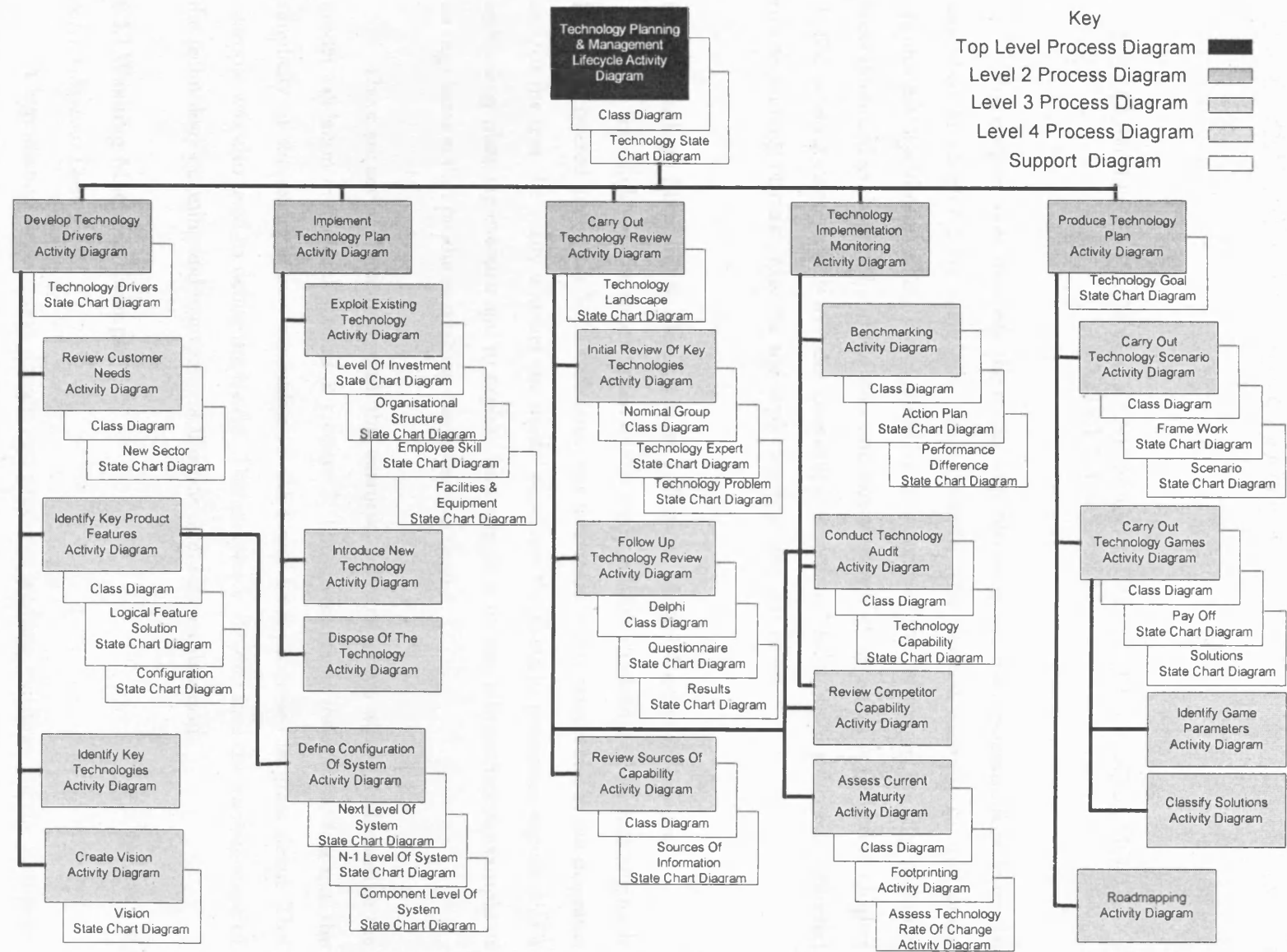
Figure 96 Performance Difference State Chart Diagram

5.3 Technology Planning & Management Lifecycle Model Integration

This chapter has detailed a Technology Planning and Management Lifecycle Model describing how all the parts of the model integrate together to produce and execute a technology plan. In summary, the hierarchy of all the UML model diagrams is shown in Figure 97 including how they fit together.

Chapter 6 will now explore this Technology Planning and Management Lifecycle Model by using a worked example. The worked example of the model ensures that it addresses all the issues raised by the review of the existing technology planning tools described in chapter 2 and the instrumentation supply chain study described in chapter 3.

Figure 97 Technology Planning And Management Lifecycle UML Model Hierarchy Diagram



6. TECHNOLOGY PLANNING AND MANAGEMENT LIFECYCLE MODEL WORKED EXAMPLE

This chapter aims to verify the technology planning and management lifecycle model described in chapter 5 by using a worked example. The worked example of the model ensures that it addresses all the issues raised by the review of the existing technology planning tools described in chapter 2 and the instrumentation supply chain study described in chapter 3. The worked example also includes checking it stimulates the thought processes expected of a technology planning exercise and exploring how easy it is to use.

6.1 Technology Planning & Management Lifecycle Model Worked Example

The traceability of the issues raised by the study and the modelling of the existing tools has been covered in chapter 5. As each issue was addressed it was referenced in the diagrams and/or the text. To verify whether the model produces the thought processes expected of a technology planning exercise and to explore how easy it is to use, a hypothetical example of an organisation that produces washing machines was used.

There are several limitations with this example, some of which will be addressed in the model validation methods described in chapter 7. These limitations include the fact that the simplicity of the example may not utilise all the lower level processes in great detail. This example was also used to debug the model. This chapter is divided into the various steps of the technology planning and management lifecycle to aid the explanation.

6.1.1 Washing Machine Example

6.1.1.1 Business Drivers

A hypothetical organisation designs and produces washing machines for the European domestic household market. These machines use standard European domestic electricity and water supplies and the unit size is compliant with the standard opening found in most domestic fitted kitchens. The machines use conventional drum, motor, programme

controller, front door lock and solenoid valve technology and use commercially available powder and water to wash clothes.

More recent editions to the washing machine range include washing machines that include a tumble dry facility. This facility utilises water vapour condensing technology to dispose of the water via the conventional waste water outlet rather than a separate hot air outlet that needs to be vented outside the building.

The organisation has seen sales decline slightly over the past couple of years due to more innovative machines being available. This decline would have been worse had the organisation not introduced the washer dryer machines. The organisation's strategy aims to stop the decline in sales and turn this decline into growth. To do this the organisation recognises it needs to introduce more innovation into its product range. A brief set of Business and Marketing Objectives are shown in Tables 23 and 24.

Business Objective	Effect	Value To Stakeholder
Increase Market Share	Grow Business	Company Share Value Increases Due To Position In Market Place
Move In To Additional Markets	Grow Business	Company Share Value Increases Due To Larger Range Of Potential Customers
Increase Turnover	Ensure Business' Survival	Secure Employee's Future
Increase Profits	More Money Available For Re-Investment (Training, R&D etc)	Employees Can Develop Through Training
		Company Share Value Increases Due To Re-Investment
	More Money Available To Pay Larger Dividend	Larger Dividend Paid To Share Holders
		Company Share Value Increases Due To Increase In Dividend

Table 23 Washing Machine Example – Business Strategy

Business Objective	Marketing Strategy	Marketing Objective
Increase Market Share	Differentiate Product Offering	State Of The Art Technical Features
		Address Environmental Concerns
		Facilitate Ease Of Customisation
	Reduce Whole Life Costs	Reduce Energy Usage
		Reduce Water Usage
		Ease Of Maintenance & Repair
		Reduce Number Of Moving Parts
Move In To Additional Markets	Explore Industrial, Hotel & Catering And Hospital Markets	Repackage Existing Offering
Increase Turnover	Increase Market Share Whilst Maintaining A High Value Product	As Above
Increase Profits	Ensure High Added Value From Product	As Above

Table 24 Washing Machine Example – Marketing Strategy

6.1.1.2 Develop Technology Drivers

In this example, the main need of the domestic customers is essentially for clean fresh clothes that are ready to wear, and not prohibitively expensive. Customers will prefer not having to go to a third party to keep clothes clean. Customers are becoming more and more concerned about the environment and therefore anything that is environmentally friendly is a selling point. Any solution will require the capacity to cope with a household of up to 6 people. Future requirements will include a reduction in energy, water and detergents usage, and clothes that do not need to be ironed or pressed manually.

This example includes how the European domestic washing machine market will change and how the existing washer/dryer may be used in other applications.

6.1.1.2.1 Review Customer Needs

The first step in developing the technology drivers is to review the customer needs. These needs provide the output of the Needs Research as a definition of the Future System Capability/Functionality. In this case the Future System Capability is as follows:

- Provide clean, dry and pressed clothes.
- Cleans clothes in a reasonable cycle time.
- Use less detergents/chemicals.
- Use less water.
- Use less power.
- Make use of cheap rate energy.
- Be compatible with existing domestic services (water, power & waste connections).
- Be capable of being installed in an existing fitted kitchen (i.e. it has to be compatible with existing domestic installation to reduce the cost of installation, for example, a supplementary £10 for fitting from the retailer).
- Reduce operational noise.

The second path through this part of the model explores the use of existing technologies in other markets, for example the transfer of the use of the cyclone vacuum system from saw mills to the domestic vacuum cleaner market. The existing washer dryer technology can be adapted to meet the needs of the industrial market, for example hospitals, hotels and commercial laundry firms by scaling up the designs, adapting to commercial power and water connection standards and adding additional monitoring controls to monitor the use of power and the amount of waste generated. These new sectors need to be checked for compatibility with the business' strategy. Any sectors that are identified and are not compatible with the business strategy should not be pursued.

For the rest of this example, the focus will be on the future needs rather than the use of existing technology in new markets. However, the application of the various parts of this model will be similar.

6.1.1.2.2 Identify Key Product Features

The future customer needs identified previously can be achieved by:

1. Disposable clothes – worn once and then thrown away (environmentally unacceptable and costly)
2. Existing fabrics cleaned and pressed
3. Self cleaning fabrics.

Discounting customer need 1 above due to environmental considerations and recognising that customer need 3 could be a long term threat to the business and therefore needs monitoring, this example will explore customer need 2 in more detail.

6.1.1.2.2.1 Define System Configuration

Using the washing machine example the following Relevance Tree of potential system configurations is depicted in Figure 98. The system level to which an organisation's tree may go depends on whether the organisation considers it a component, easily sourced from a ranger of suppliers, or whether it is sufficiently novel, risky and critical to the success of the system to be controlled internally.

Starting at the top, the system is a clothes cleaner with the system functions of; clothes ironing/press, clothes dryer, clothes washer, some form of control and how the system is installed. This is not an exhaustive list as the aim is not to design the system, which would require a big and complicated relevance tree, but to identify the key features and potential solutions.

Taking the system function of wash clothes, there are two solutions proposed for the next level of the systems structure – the conventional system and an ultrasonic system. The conventional method uses a rotating drum, heated water and motor to rotate the drum. Even with the conventional washing system there is opportunity for new technologies to be introduced, for example the use of two drums that counter rotate (reducing vibration and noise). This is the approach used by Dyson on their new washing machines.

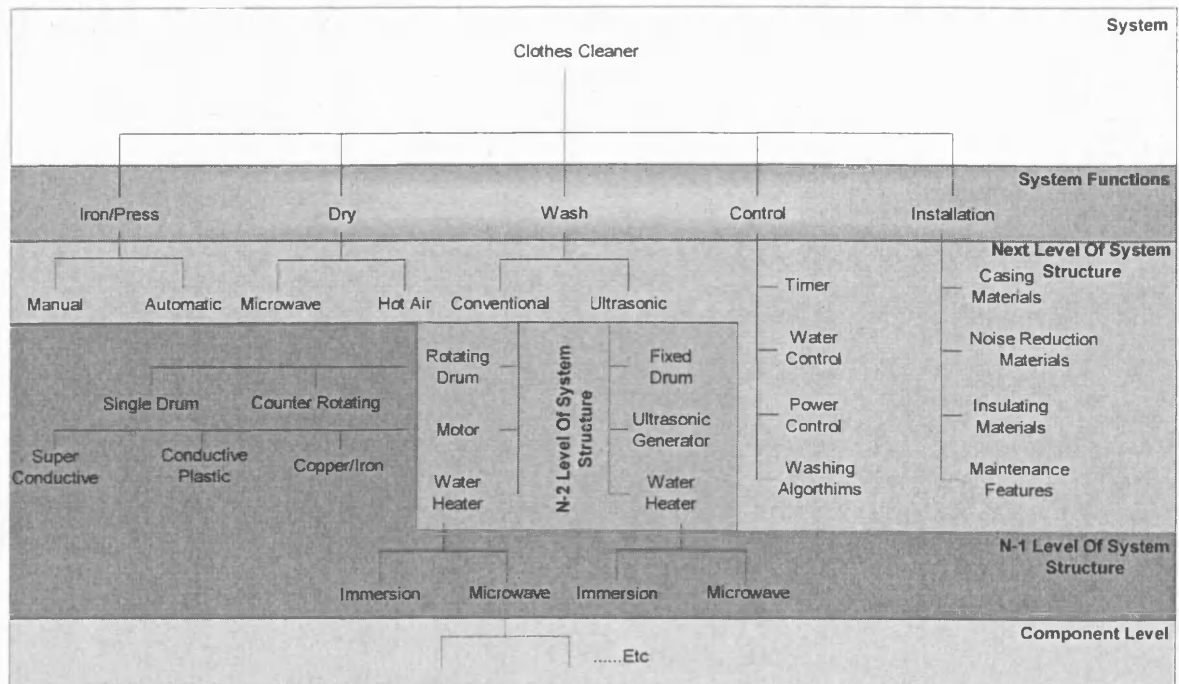


Figure 98 Washing Machine Example Relevance Tree Diagram

This process continues until the tree represents all the system solutions for each level of the system that are of interest to the organisation. All the options are reviewed and a proposed system configuration is selected. For the washing machine example the following configuration has been selected and is represented in Figure 99.

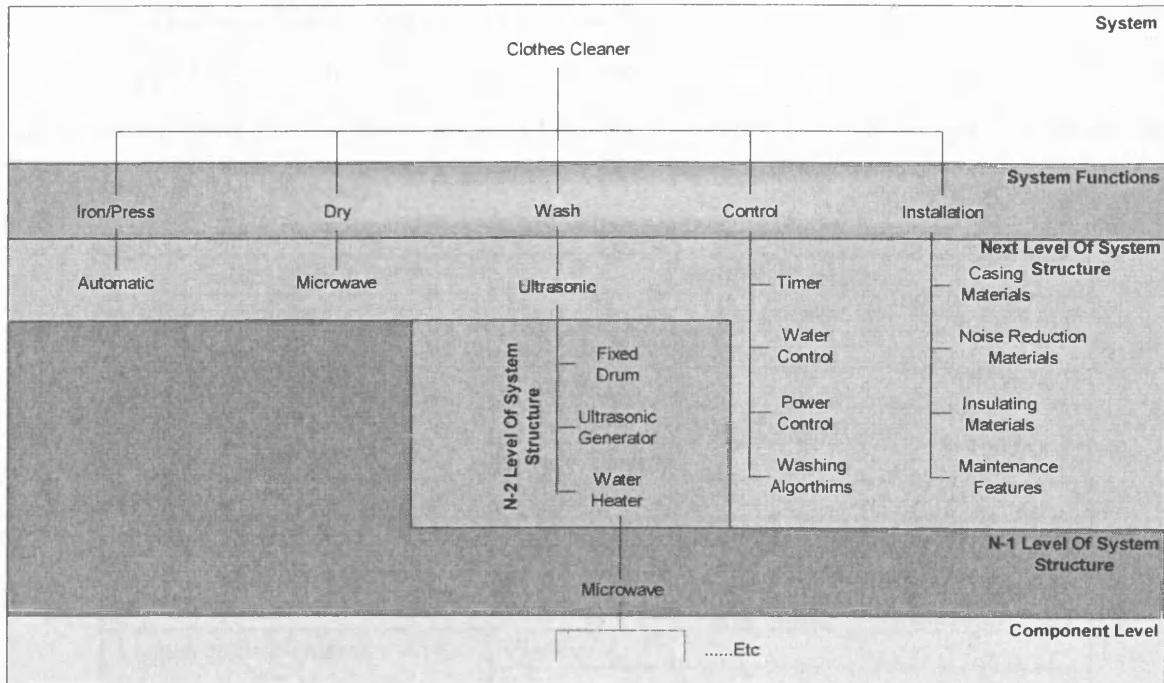


Figure 99 Washing Machine Example Selected Relevance Tree

6.1.1.2.2.2 Abstract Salient Features

Using the output from the relevance tree exercise, a list of salient features of the technical structure is abstracted. In the washing machine example shown in Figure 99 the following salient technical features are required:

- Microwave water heating.
- Microwave clothes drying.
- Incorporated automatic clothes ironing/pressing.
- Lightweight housing.
- Low noise.
- Efficient.
- Easy to install and maintain.
- Improved Programme Algorithms.

6.1.1.2.2.3 Generalise Logical Alternatives For Each Feature

Using the salient features listed above, the following logical alternatives have been identified in Table 25. The development of this list is difficult to do in any great detail due to the author's lack of knowledge in this field.

Salient Feature	Logical Alternative
Ultrasonic Washing	Piezo Electric Transducers
	Sub Aqua Speakers
Microwave Water Heating	Magnatron
	Next Generation of Magnatron?
	Mode Stirring
Microwave Clothes Drying	As Above
Incorporated Automatic Clothes Ironing/Pressing	Anti-Wrinkle Fabrics
	Some Form Of Physical Pressing System
	Another Form Of Ironing Technique?
Lightweight Housing	Plastic
	Aluminium Alloys
	Space Frame Structure
Low Noise	Use of Acoustic Materials
Efficient	Ultrasonic Washing Reduces Need For A Motor To Move Drum.
	Microwave Heating/Drying Removes Need To Heat Surrounding Air.
	Use Of Insulating Materials
Easy To Install And Maintain	'Design For' Techniques (e.g. Manufacture, Reliability, Availability, Testability And Installation)

Table 25 Washing Machine Example – Generalise Logical Alternatives

6.1.1.2.2.4 Analyse Combinations Of Logical Features

As previously described, a Quality Function Deployment (QFD) diagram is a useful tool to analyse the combinations of the logical features of the future system. The diagram facilitates the trade off between the needs of the customer and the needs of the organisation carrying out the technology planning. For this washing machine example a QFD diagram is shown in Figure 100.

[illegible]

Figure 100 Washing Machine Example QFD Diagram Used To Trace The Salient Features Of The System Back To The Customer And Business Requirements

This example highlighted a limitation with the QFD diagram in that it is not easy to address multiple mapping and overlapping technologies and benefits, for example value for money and reduced cycle time. It might be possible to use the QFD diagram to bundle up benefits for example:

Technology Bundle	Bundle Includes			Cost
	Technology 1	Technology 2Technology n	
A	Ultrasonic Washing	Microwave Drying	Etc.	C _A
B	Etc.	Etc.	Etc.	C _B
C				C _C
D				C _D

Table 26 Washing Machine Example – QFD Technology Bundles To Overcome Overlaps

Needs	Technology Bundle			
	A	B	C	D
N1	Low Maintenance	Etc.		
N2	Efficient	Etc.		
N3	Etc.	Etc.		
Wants				
W1	State Of The Art	Etc.		
W2	Low Environmental Impact	Etc.		
W3	Etc.	Etc.		

Table 27 Washing Machine Example – QFD Technology Bundles Addressing Multiple Needs And Wants

This example also highlighted that it is useful to treat the model iteratively through a number of review passes in order to eliminate unpromising technologies early, for example ones that have not real value.

6.1.1.2.3 Identify Key Technologies

Initially the ideal set of technological solutions are identified, see Table 28, and then these ideal solutions are examined for contradictions, see also Table 28. Please note this is not an exhaustive list and is just for illustration only.

Salient Feature	Key Technology	Conflict
Ultrasonic washing	Piezo Electric Transducers	Transducers interfering with the microwave devices
	Sub Aqua Speakers	Transducers interfering with the microwave devices
Microwave water heating	Magnetron	Microwave devices might interfere with Ultrasonic Transducers
	Next Generation of Magnetron?	
	Mode Stirring	Might interfere with Ultrasonic Transducers
Microwave clothes drying	As above	As above
Incorporated automatic clothes ironing/pressing	Anti-wrinkle fabrics	Beyond the scope of this business , however will impact the ironing functionality if successful
	Some form of physical pressing system	May interact with the Microwave devices and Ultrasonic Transducers
	Another form of technique?	May interact with the Microwave devices and Ultrasonic Transducers
Lightweight Housing	Plastic	Use of plastics to form a Microwave heating chamber will need to be explored
	Aluminium Alloys	
	Space Frame Structure	
Low Noise	Use of acoustic materials	
Efficient	Ultrasonic washing reduces need for a motor to move drum.	As above
	Microwave heating/drying removes need to heat surrounding air.	As above
	Use of insulating materials	
Easy to install and maintain	'Design For' techniques (e.g. manufacture, reliability, etc.)	

Table 28 Washing Machine Example – Key Technologies And The Conflicts Between Them

6.1.1.2.4 Create Vision

The vision for the washing machine example might be:

‘Our aim is to produce an efficient washing, drying and ironing machine that utilises the latest technology. To achieve this end we will be investing in developing ultrasonic washing, microwave drying and an ironing process.’

This vision would need to be communicated throughout the organisation by the most appropriate means. Due to the hypothetical nature of this example, this part of the model cannot be fully verified.

6.1.1.3 Carry Out Technology Review

The following sections describe the Carrying Out Technology Review part of the process as applied to the washing machine example.

6.1.1.3.1 Initial Review Of Technologies

This part of the process cannot be easily verified by simply using the washing machine example. To enable this example to be walked through the Technology Planning and Management Lifecycle Model, a hypothetical nominal group meeting of experts produced the results depicted in Table 29.

Problem Presented	Solutions Tabled	Solution Ranking
Ultrasonic Washing	Piezo Electric Transducers	1
	Sub Aqua Speakers	2
Microwave Water Heating	Magnetron	1
	Next Generation Of Magnetron?	2
Incorporated Automatic Clothes Ironing/Pressing	Anti-wrinkle Fabrics	2
	Some Form Of Physical Pressing System	1
	Another Form Of Ironing Technique?	3
Lightweight Housing	Plastic	1
	Aluminium Alloys	2
	Space Frame Structure	3
Low Noise	Use Of Acoustic Materials	1

Table 29 Washing Machine Example – Results Of Nominal Group Exercise

6.1.1.3.2 Follow Up Review Of Technologies

Again this part of the process cannot be easily verified by simply using the washing machine example and therefore it has been decided not to use this part of the model. This is the sort of decision organisations will make when tailoring the model to suit their purposes and hence, this will be how the model will be implemented in practice. Elements will be mixed and matched according to the needs of the implementing organisation. The important essence of the model is that it provides a framework in which to select the appropriate tools and that the decisions made not to use elements of the model are done actively and are recorded for future reference.

6.1.1.3.3 Assess Current Maturity Level

As described in the previous chapter, this comprises of assessing the competitive impact and position, the rate of change, and the readiness of the technology.

6.1.1.3.3.1 Assess Technology's Competitive Impact And Position

Selecting Piezo Electric Transducer from the list of technologies from the washing machine example, this technology was identified as being a 'pacing technology' in this application. It is felt that it is a pacing technology as it is fairly new, but is likely to have a high impact on competitive advantage, although the technology is well developed in other areas. The organisation's competitive position in this technology was also identified as being weak. The organisation is clearly behind the competitors. However, it does not spend its time in a short-term fire-fighting role making the definition for a weak market position, used in chapter 2, a bit awkward to use. In addition when using the footprinting model there was no scope in definitions of competitive positions for a 'null' position. This position is where nobody in the market is in a strong position therefore everyone is starting from a weak position.

The Piezo Electric Transducer technology was plotted on a competitive impact/position matrix, see Figure 101. An arrow showing the direction the organisation needs to move in is also shown.

This process would be repeated for all the technologies identified that are of interest to the organisation.

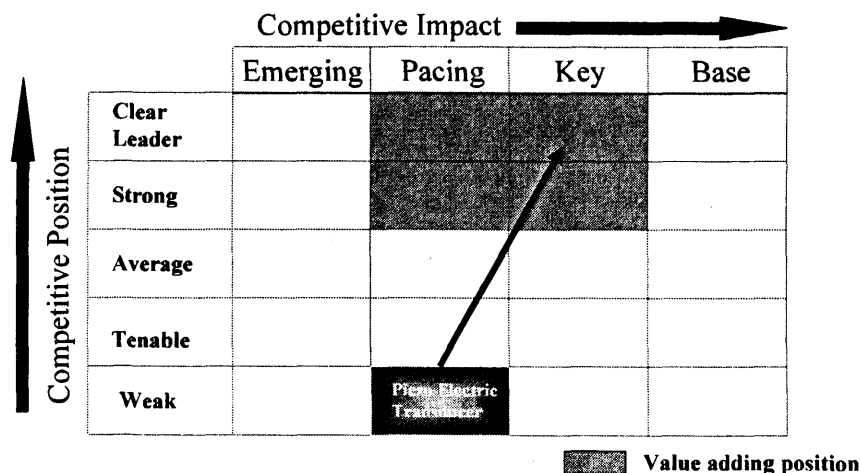


Figure 101 Washing Machine Example – Competitive Impact Matrix

6.1.1.3.3.2 Assess Rate Of Change Of Technology

Again using the Piezo Electric Transducer from the list of technologies from the washing machine example, the rate of change shown in Figure 102 is estimated. Ultrasonic cleaning is already used in the cleaning of industrial items, for example Printed Circuit Boards, however it is not developed for use in the cleaning of clothes. The technology requires developing in order to be used in a domestic washing machine. The aim of this technology is to provide an alternative to a rotating drum to reduce power consumption and remove the moving parts which are prone to wear.

Using the equation from chapter 2, the following variables have been researched:

$$I = \frac{qN_0^2(e^{2t}-1)}{4c}$$

where

I = information (state of knowledge)

t = time - (in this example it is over 10 years)

q = average productivity factor per investigator and time unit (80% for this example)

N_0 = number of investigators engaged at time $t = 0$ (assuming 5)

c = coefficient (slope of curve in logarithmic plot) (assuming a coefficient of 0.1)

This gives the predicted trend shown in Figure 102.

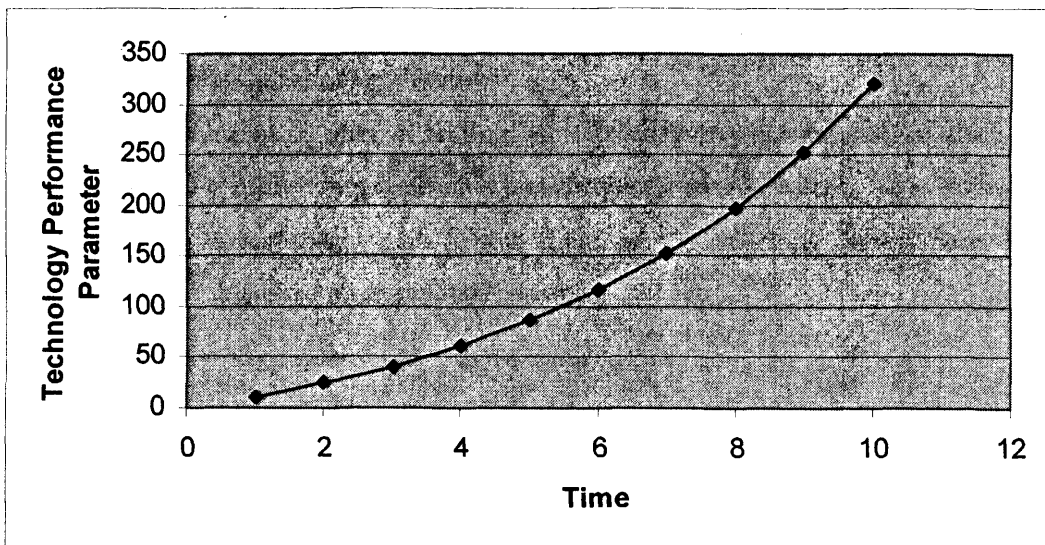


Figure 102 Washing Machine Example - Piezo Electric Transducer Trend Model

6.1.1.3.3.3 Assess Technology Readiness

Again using the Piezo Electric Transducers from the list of technologies from the washing machine example, the Technology Readiness of this technology is deemed to be between 2 (technology concept and/or application formulated) and 3 (analytical and experimental critical function and/or characteristic proof-of-concept). For this organisation the technology readiness of Piezo Electric Transducers is level 2, however, for the organisation's competitor it is estimated that they are ahead of the game and therefore their technology readiness for Piezo Electric Transducers is level 3.

6.1.1.3.3.4 Conduct Technology Audit

This part of the model is difficult to demonstrate by this hypothetical example. If a technology audit was carried out it would show that the organisation does not have the knowledge and capability required to develop the ultrasonic washing technology. However, it would not be difficult to develop this capability in-house and therefore any decisions regarding the development of ultrasonic wash should strongly consider developing the capability in-house.

6.1.1.3.3.5 Review Competitor Capability

This part of the model is again difficult to demonstrate by this hypothetical example. If a review of competitor capability was carried out it would show that at least one of the organisation's competitors does have the knowledge and capability required to develop the Piezo Electric Transducers technology and has already made some considerable progress.

6.1.1.3.3.6 Review Source Of Technology Capability

A simple review of sources of technology capability was carried out using an internet search. In practice a more comprehensive search would be conducted. This review would also be carried out continuously. This review identified the following organisations who are working with technologies of interest to this example:

Underwater Speakers – Lubell Labs Inc. based in Columbus, Ohio have been working with underwater loud speakers mainly for music in the leisure and entertainment industry.

Ultrasonic Clothes Washing – The Fraunhofer Technology Centre in Hialeah, Florida are looking for a partner to take their development approach to ultrasonic washing of clothes to the next stage.

Ultrasonic Clothes Washing – Sanyo Electric Co Ltd have a fully automatic ultrasonic washing machine. They are a potential competitor and a source of expertise.

Ultrasonic Clothes Washing – Lawrence Berkeley National Laboratory have been working with the US Department of Energy exploring various improvements in washing machine design including ultrasonic washing.

Piezo Electric Transducers – Murata Manufacturing Co Ltd, Kyoto, Japan specialise in Piezo Electric Transducers.

6.1.1.3.7 Prepare Technology Forecast

The technology forecast summarises the findings from the technology reviews, the technologies' maturity and impact, the sources of capability and what the competition are doing, see Figure 103. This is required for the Technology Planning Phase.

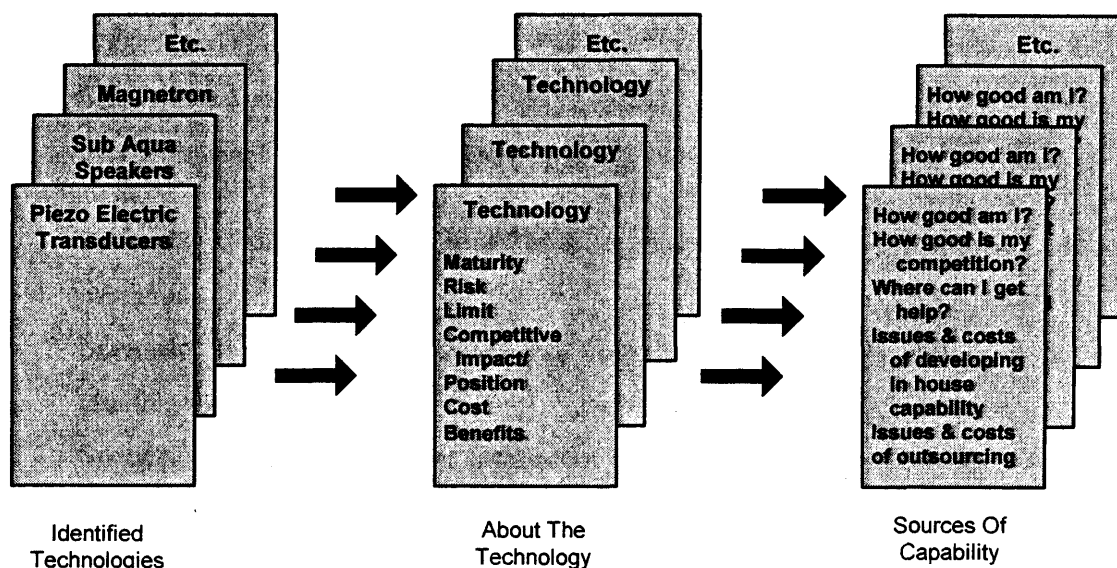


Figure 103 Washing Machine Example – Technology Forecast

6.1.1.4 Produce Technology Plan

The following sections describe the Produce Technology Plan part of the process as applied to the washing machine example.

6.1.1.4.1 Carry Out Scenarios

The framework for the scenarios has already been defined as part of the developing technology drivers and the review of technologies. This scenario will focus on the development of ultrasonic washing.

6.1.1.4.1.1 Identify Sequence Of Events

The sequence of events and key decisions for ultrasonic washing are as follows:

1. Decision to develop ultrasonic washing.
2. Concept and feasibility development of piezo electric transducers for this application.
3. Concept and feasibility development of subaqua moving coil speakers.
4. Advantages and disadvantages of both technologies assessed.
5. The best all round technology is selected for development for use in the product.

6.1.1.4.1.2 Identify Scenarios

The following limited set of scenarios was identified:

Scenario 1: Competitor A launches a commercially attractive ultrasonic washing machine.

Scenario 2: Early ultrasonic washing machines are unreliable and produce poor cleaning results.

Scenario 3: The government introduces new legislation to reduce the amount of detergent that can be used by domestic washing machines.

6.1.1.4.1.3 Identify Consequences

The following consequences for each scenario were identified:

Consequence 1: Ultrasonic wash gains market acceptance and competitor A gains a market lead and hence market share. The market for ultrasonic washing machines is stimulated opening the door to other manufacturers.

Consequence 2: The majority of customers are 'put off' buying ultrasonic washing machines and hence ultrasonic washing fails to gain sufficient interest in the domestic machine market.

Consequence 3: Conventional washing machines are unable to clean clothes to the desired standard under the new regulations. Ultrasonic washing meets both requirements and hence the market for domestic machines is stimulated.

6.1.1.4.1.4 Review Scenarios/Consequences To Make R&D Decisions

Consequences 1 and 3 would provide an attractive proposition to the organisation to invest in ultrasonic washing as both scenarios would stimulate market demand. The organisation could invest in ultrasonic washing technology to ensure that competitor A does not gain too strong a position in the market. If the organisation brought out a machine close to competitor A's launch, this would ensure that competitor A does not gain too strong a position.

Initially, consequence 2 would look unattractive to invest in ultrasonic washing technology. However, if the organisation were to invest, it may overcome the short comings of the existing washing machines and hence put itself in the position of competitor A in scenario 1. If the organisation does not invest in ultrasonic washing technology it will get left behind and may struggle to recover should scenario and consequence 1 occur.

Given all three scenarios, the decision would probably be to invest in ultrasonic washing machine technology in order to establish whether it is likely to be commercially competitive. The main decision to be made is how much to invest and in which of the technologies that can provide the ultrasonic washing capability.

These scenarios can then be explored using game theory before being translated into a roadmap, see later section, and the consequences are used as part of the cost benefit analysis and decision making, see later section.

6.1.1.4.2 Carry Out Technology Games

The use of technology games in this washing machine example is limited to the scenarios above.

6.1.1.4.2.1 Establish Game Structure

This establishes the time sequence of the game moves. For example, are decisions made simultaneously without viewing what the competitor(s) is going to do or do you have time to react to competitor(s) decisions. For this example, decisions are made simultaneously, however, there will be an annual review process that can react to the results of decisions made in the intervening period.

6.1.1.4.2.2 Identify Players

Using the three scenarios described previously, the players in this example are the organisation concerned and competitor A. The government could be considered as a player, given their influence in the market place through legislation and it is also understood that there would possibly be several competitors in the domestic washing machine market. However, for simplicity of the example only competitor A and the organisation will be considered.

6.1.1.4.2.3 Identify Strategy Space

The options available in the strategy space can be very comprehensive. However, for this example, the options available to the organisation and competitor A are whether to invest in ultrasonic washing technology or not.

6.1.1.4.2.4 Create Payoff Matrix

Given the two players and the two options, the following payoff matrix is generated:

	Options	
	Invest In Ultrasonic Washing	Do Not Invest In Ultrasonic Washing
Organisation	(Increase Market Share)	(No Market Share)
Competitor A	(Increase Market Share)	(No Market Share)

Table 30 Washing Machine Example – Payoff Matrix

6.1.1.4.2.5 Classify Solutions

Not to invest in ultrasonic washing for both organisations could be considered strictly dominated strategies as they would be in neither organisations' interest. As a result, investing in ultrasonic washing technology for both organisations could be considered in Nash equilibrium as both organisations would probably pursue the investment regardless of the other. Ideally the best outcome for the organisation is if it invests and competitor A does not. Both investing would duplicate development and may not lead to either one gaining a competitive advantage given the level of investment made.

6.1.1.4.3 Translate Games And Scenarios Into Roadmap

The scenarios listed above are transferred into a roadmap for each scenario. For this washing machine example a single roadmap has been generated for a single scenario for ultrasonic washing, see Figure 104. The generation of roadmaps would be carried out for all scenarios for all technologies. These roadmaps provide a good summary to senior management as part of the cost benefit analysis and decision making process.

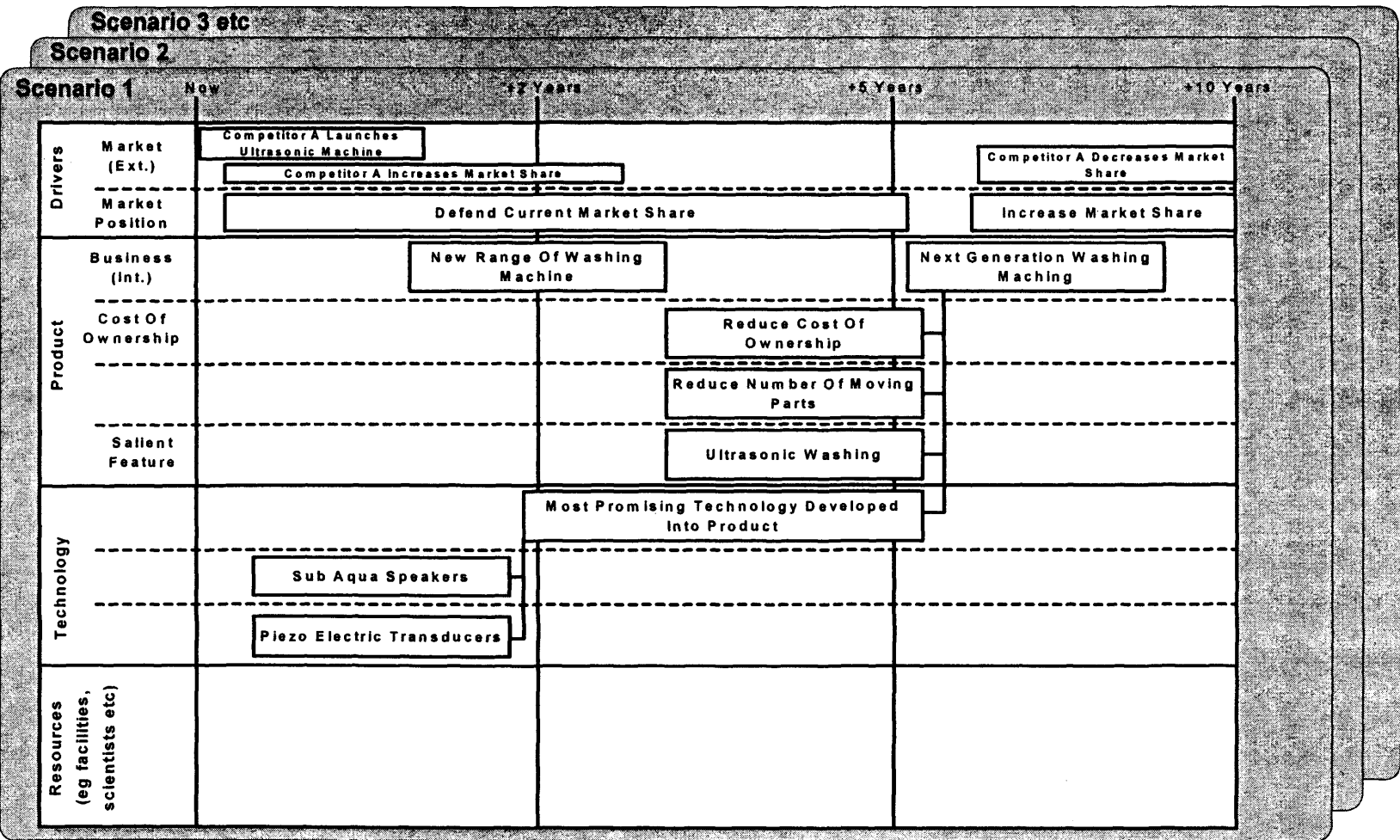


Figure 104 Washing Machine Example – Technology Roadmap Using The T Plan Template From The Institute for Manufacturing, University of Cambridge (Phaal et al, 2001)

6.1.1.4.4 Perform Cost Benefit Analysis And Decision Making

All the information collated and processed by the process so far is used to make technology research and investment decisions. Using the washing machine example and the limited information generated, a cost benefit model was generated, see Figure 105 (based on models developed for the ISCAM project by M Emes, D Cowper & A Smith).

The model was generated by selecting a number of parameters of interest from the example QFD, Figure 100 in section 6.2.1.2.2.4. For each of the parameters selected; the minimum acceptable and ideal values were identified, how much more attractive the ideal value is than the minimum was established, what the weighting factor is for each parameter was estimated. Ideally this would be carried out in conjunction with the stakeholders and each stakeholder group would have a particular view on the values and weightings.

Technology Solution Evaluation

MIN IDEAL IDEAL_Weight	Solution Attributes							Implementation Factors		
	Cleaning cycle time (mins)	Amount of detergent/ chemicals used	Amount of Water Used	Unit Cost	Reduce Noise (dB)	Amount of Electricity Used (kWh)	Reduce maintenance costs by	Cost (£)	Time to Develop (yrs)	Impact on Products
	40	50%	30%	400	3	1.5	30%	50000	4	70%
	30	30%	10%	250	6	1	50.0%	30000	0	100%
	2	1	1.5	4	3	2	3	1	3	1
Proposed Solution										
Ultrasonic Washing (Piezo)	35	10.0%	5.0%	380	4.5	1.50	50.0%	45000	5	0%
Ultrasonic Washing (Sub Aqua)	35	10.0%	5.0%	390	4.5	1.50	50.0%	55000	6	0%
Microwave Water Heating	30	10.0%	5.0%	350 000	3	1.00	30.0%	20000	2	0%
etc	40	1%	5.0%	500 000	3	1.00	1.0%	0	0	0%
E	40	1%	5.0%	500 000	3	1.00	1.0%	0	0	0%
F	40	1%	5.0%	500 00	1	1.0	1.0%	0	2	0%
G	40	1%	5%	500 00	1	1.00	1.0%	0	2	0%
H	40	1%	5.0%	500 000	1	1	1.0%	0	1	0%
I	40	1.0%	5.0%	500	1	1.00	1.0%	0	6	0%
										Overall Value
										32.25
										25.48
										14.66
										0.00
										0.00
										0.00
										0.00
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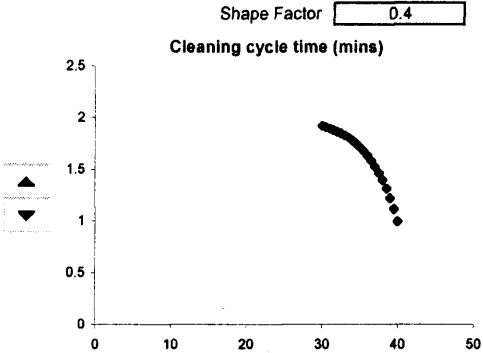
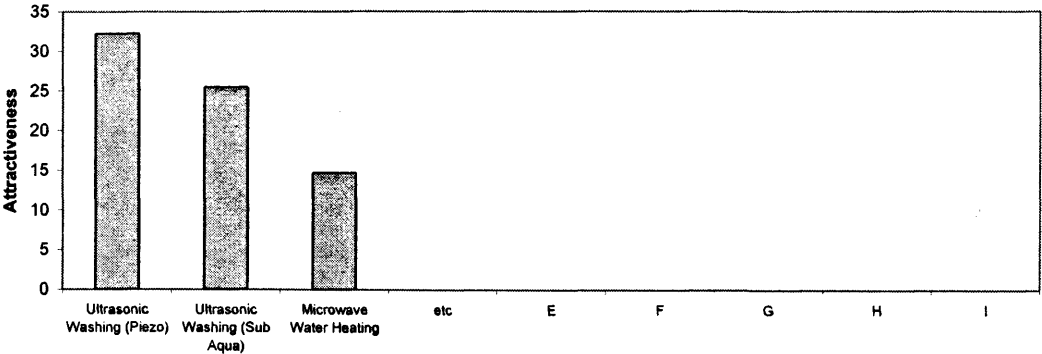


Figure 105 Washing Machine Example – Technology Cost Benefit Analysis
(Based On Models Developed For The ISCAM Project By M Ems, D Cowper & A Smith)

The cost benefit model then assumes an exponential decay function of the form $1-1/e^x$ building from the minimum value of the parameter to the ideal. This gives a curve of the attractiveness versus parameter profile. A fully developed tool is offered as part of the technology planning tool box, see chapter 8, which has a range of attractiveness versus parameter curves (not just an exponential decay).

For each potential solution a score against each parameter is given. From the model one could then ascertain where on the curve of attractiveness versus parameter value each solution fell for each parameter. The value of the solution could then be calculated as the product of the attractiveness scores against each parameter. A product is used instead of a sum, because a product is equivalent to a logical AND, consistent with a situation where adequate scores against all of the parameters are required. This gave overall 'attractiveness' values as shown in the graph in Figure 105. The 'attractiveness' of each proposed solution can then be considered against the implementation factors of investment cost, time to develop and impact on the product/production process.

This model should also be used in conjunction with the scenarios and consequences generated. A research and development investment plan can then be selected along with contingency plans, should either assumptions made be unfounded or the technology environment change. The selected scenario roadmaps will then form the basis of the technology plan.

At this stage the various technology measures need to be defined and milestones established. Some of the measures will be defined from the parameters identified in the cost benefit model. This will allow monitoring of progress and to test any assumptions made. In the washing machine example the technology measures might include predictions and/or actual values for:

- Cleaning cycle time (mins).
- Amount of detergents/chemicals used.
- Amount of water used.
- Unit cost.
- Reduce noise (dB).
- Amount of electricity used (kW/h).

- Reduce maintenance costs by £x.

6.1.1.5 Implement Technology Plan

The implementation phase of the Technology Planning and Management Lifecycle Model is difficult to verify using the hypothetical washing machine example. It has also been noted that this has implications for the field trials phase of this thesis.

6.2 Conclusion And Issues Raised

Using the hypothetical washing machine example to test the technology planning and management lifecycle model, the model appears to cover the issues in a logical sequence and could be useful. This example raised the following issues:

- The model requires tailoring to meet the needs of the context in which it is applied. For example, the lower level detail of the model will depend on implementation and adaptation for each particular organisation and industrial sector.
- The model needs to be presented in a form that can be digested by the user(s). Using a UML model may be a barrier to understanding the process. Additional information to aid the use of the model, for example check lists etc, was also identified.
- Any technology planning MUST include contributions from the stakeholders and experts with detailed knowledge of the technology, product(s) and market. The author's limited knowledge in the field of washing machines was very much exposed by walking through this example.

The washing machine example also highlighted that the approach to validating the technology planning and management lifecycle model needed to be revised. It is difficult to verify and validate the whole model in the time available for this project. The validation would also require the full co-operation of any participating organisation to carry out the technology plan implementation trial. It was decided to use a series of workshops with different organisations to field test some of the concepts of the model and to use the experience to refine the model.

The following chapter (7) will now explore the field trials used to test and refine the technology planning and management lifecycle model described in chapter 5.

Chapter 7

7. TECHNOLOGY PLANNING AND MANAGEMENT LIFECYCLE MODEL FIELD TRIALS AND REFINEMENT

This chapter describes the field trials used to test and refine the technology planning and management lifecycle model described in chapter 5. The field trials were first conducted with the Solar Physics group from University College London's (UCL) Mullard Space Science Laboratory (MSSL) to refine the model before being tested on the two industrial organisations.

7.1 Field Trials

The field trials consisted of a set of technology planning workshops, mainly covering the first part of the technology planning and management lifecycle model. A variety of formats were tried, for example a one-day, two half-day, and two full one-day workshops. Each workshop consisted of a series of short presentations to define terms and to explain the process followed by either syndicate activity by the delegates or a facilitated group discussion. Each specific workshop is detailed in the following sections.

The workshops were led by the author with assistance from Prof Alan Smith and Dr Michael Emes who aided the discussions, facilitated the syndicate groups and collected and process information/data 'live' during the workshop to provide the delegates with feedback.

To address the issues raised by the washing machine example described in chapter 6, the UML model of the technology planning and management lifecycle was converted into a block diagram form, Figure 106, and the lower level processes adapted to each workshop.

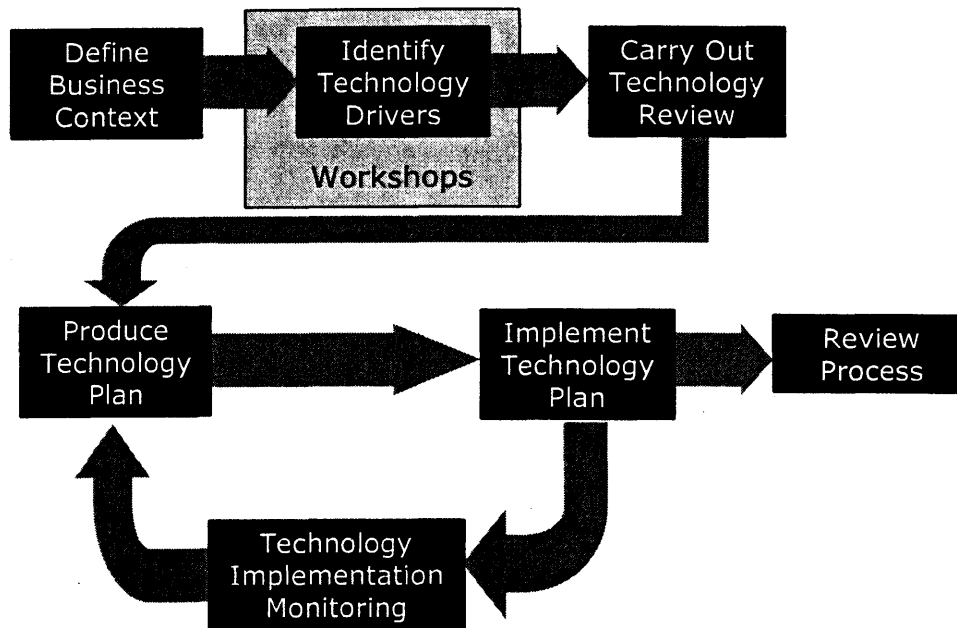


Figure 106 Technology Planning And Management Lifecycle

7.2 Technology Planning and Management Lifecycle Model Measures

The following measures for the Technology Planning and Management Lifecycle Model were identified:

Technology Impact:

- How much does technology affect your business?

Ease of use:

- Is the model straightforward and easy to follow?
- Is the model easy to apply?

Benefits of the model:

- Does the model help with justifying technology investment decisions?
- Does the model help you get started in managing technology?
- Did the model reveal technologies you didn't know about or even consider?

These measures are mainly qualitative and were tested by exploring them with the workshop delegates by questionnaire, see appendix 9. The questionnaire was given to the

delegates to complete prior to the first workshop commencing. The same questionnaire was then given to the delegates to complete at the end of the workshop(s).

7.3 MSSL Solar Physics Group Technology Planning Workshop

The format of the MSSL Solar Physics Group technology planning workshop consisted of two full-days with the following objectives:

- To guide those involved in Solar Physics at MSSL through the first part of the technology planning and management lifecycle model.
- At the end of day one; to have explored what technologies the Solar Physics Group need and what technologies are available.
- At the end of day two; to have drafted a technology plan that will define how the Solar Physics Group might acquire such technologies.
- To help the author validate the technology planning model, to assess its usefulness and identify areas of improvement.

To achieve these objectives the first part of the Technology Planning and Management Lifecycle Model, Figure 107, was adapted and used. The workshop:

- Explored the Solar Physics Group's Business Context.
- Identified the Solar Physics Group's Technology Drivers.
- Carried out a Review of the Solar Physics Group's Technology.
- And Produced a Technology Plan.

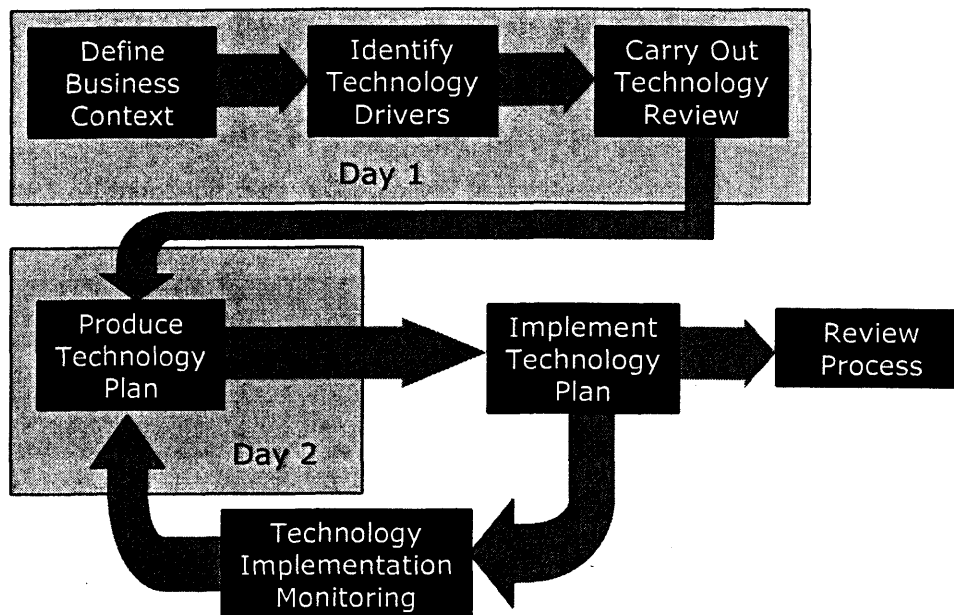


Figure 107 Aspects Of The Technology Planning And Management Lifecycle Used By The MSSL Workshops

7.3.1 Business Context

This first stage of the process sets the context and constraints for the technology planning exercise. The definition of the Solar Physics Group's business context was carried out as a syndicate exercise where the delegates had to:

1. Determine their main area of interest (What business am I in?)
2. Determine who their stakeholders are and what are their requirements?
3. If their organisation is part of a larger group, what are their overarching requirements?
4. Given these constraints/requirements they needed to define a weighting scheme for the technology planning process.

7.3.2 Technology Drivers

The identification of the technology drivers (Figure 108) consisted of:

1. Reviewing the Customer needs (solution objectives) (e.g. what are the key issues in Solar Physics that the group can address)?

2. Identifying the Key Product Features (technology capability) that will satisfy those needs (e.g. what would the group have to measure to answer such questions and what level would be competitive)?
3. Identifying Key technologies (technology solution) (e.g. how the group will make the measurements?)?

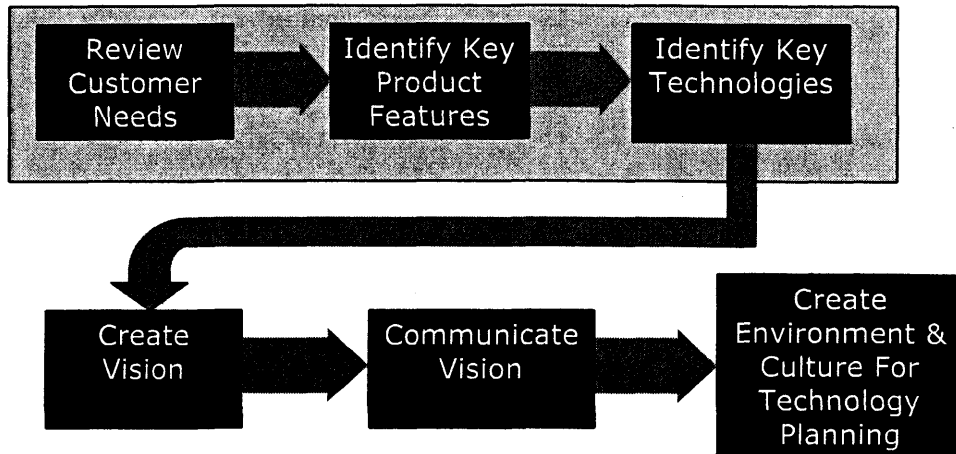


Figure 108 Identify Technology Drivers Process

7.3.3 Technology Review

The delegates had to carry out a mini technology review as a syndicate exercise using the technology drivers generated by the previous syndicate exercises, see Figure 109.

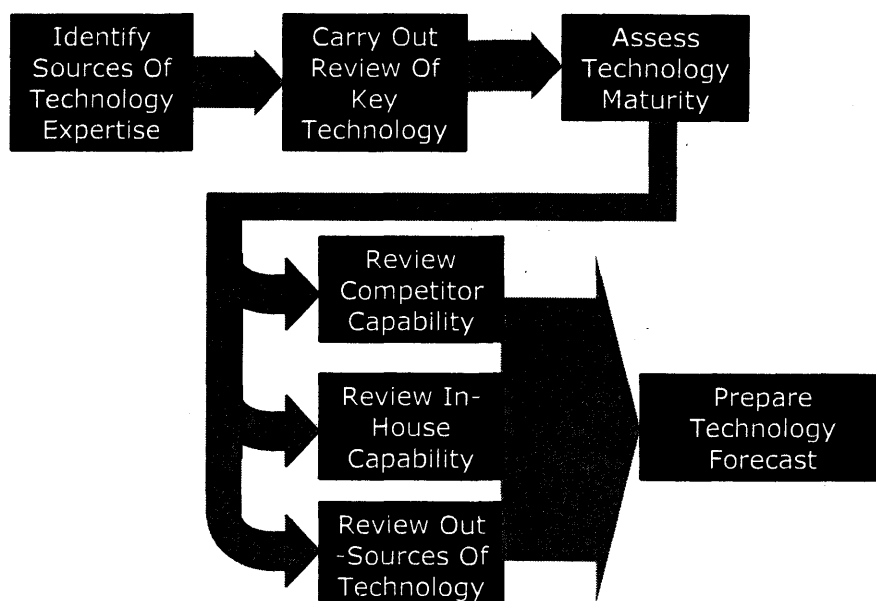


Figure 109 Carry Out Technology Review Process

The aim of the exercise was to develop a table which answers key questions about each driver for example:

- What are the technology options?
- Who owns them?
- Where are they in their lifecycle/maturity?
- What is the competitive impact?
- What is the relative cost, level of risk, natural limit, rate of change?
- How good are my competitors at this technology?
- How good am I at this technology? (Competitive Position)
- Who else is expert in this technology?
- Can I collaborate with or buy it from them?

However, due to time constraints and the practicalities of performing a technology review, this exercise was replaced with a recap on what the stakeholders would think about the technology discussed.

7.3.4 Technology Plan

This part of the process was carried out on the second of the one-day workshops. The second one-day workshop recapped some of the outcomes from the first workshop and explored two possible technology solutions in more depth.

The production of the technology plan was adapted from the process shown in Figure 110 and consisted of the following:

1. Mission Process: explored the key steps in the process from a MSSL Solar Physics mission concept to a launch, what the timescales for each part of the process are, what the key decision gates in this process are and who makes the decisions at each gate?
2. Key Stakeholders & Their Requirements: review of the list of stakeholders from the previous workshop to rank them in order of importance. The requirements (from day one) of the top 8 key stakeholders were then ranked

from 0 to 10 with 10 being twice as important as 5. These rankings were used later to analyse the cost and benefits for the two technology options.

3. Technology Solutions: The following two technology solutions (based on outcomes of first workshop) were reviewed and consolidated into a list of issues to be considered further. The relative costs for each solution were also estimated.

- Mission Concept
 - Network of spacecraft in Solar Orbit
- Capability
 - In-situ: Electron/Ion; Magnetic field
 - Full Sun Spectral Measurement
- Technical Challenges
 - Mass, power, telemetry
- Option 1
 - High cost, few very capable spacecraft, evolutionary (e.g. 3-4 super Solar Orbiter/SOHO's)
- Option 2
 - Low cost, many spacecraft with limited capability, focused, on-board intelligent, revolutionary (science craft)

4. Rating of Technology Solutions: Each of the two potential technology solutions were scored against the top stakeholder requirements identified previously. The approach considered was to satisfy the key stakeholders as a primary objective and then to address the needs of the other stakeholders.

5. Technology Scenarios: The effects on the scores from the previous exercise were considered for each of the following scenarios:

- i. MSSL's standing within the space community remains roughly constant over the next 10 years. Government investment in space research remains steady and therefore the amount PPARC would invest in MSSL for research remains comparable with today.

- ii. A concern over possible links between solar events and human health increases the level of government funding for projects investigating solar /plasma physics. MSSL plays a leading role, resulting in a doubling in the size of MSSL's solar physics programme in 10 years.
 - iii. Findings from planetary probes generate interest that leads to an increased emphasis on planetary exploration. Funding for space research for non-planetary missions is cut to approximately half current levels by 2014.
6. Technology Roadmap: The preferred technology option was selected from the cost and benefit analysis to be taken forward with a technology roadmap. The roadmap was plotted against the mission process defined in exercise one of the second workshop. The aim of this roadmap is to provide the MSSL Solar Physics group with a technology plan for pursuing the preferred technology option should they choose to adopt it as part of their future plans.

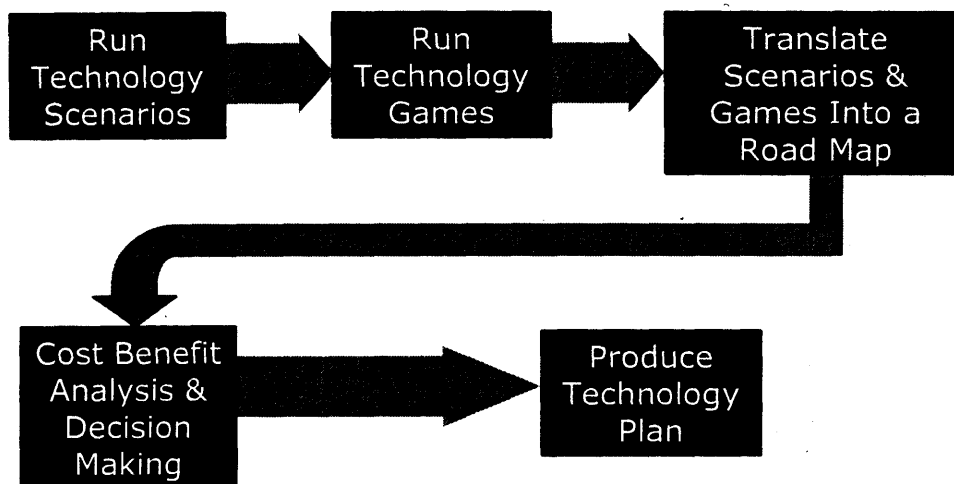


Figure 110 Produce Technology Plan Process

7.3.5 MSSL Solar Physics Group Workshop Outcomes

Using the adapted Technology Planning and Management Lifecycle Model process for the MSSL Solar Physics workshop the following outcomes were achieved:

7.3.5.1 Business Context

1. Determine their main area of interest (What business am I in?)

The Solar Physics Group is in the business of the science of solar physics and the group achieves its science objectives by:

- Writing Proposals
- Research/Theory
- Employing Post Doctorates/Students
- Commissioning/Flying Instruments
- Forming Collaborations
- Sitting on Panels
- Public Understanding of Science Activities.

2. Determine who their stakeholders are and what are their requirements?

The workshop stakeholder analysis can be found in Table 31.

The influential stakeholders and how Solar Physics influences them are given in Table 32. The stakeholders' constraints are also given in Table 32.

Stakeholders Requirements	PPARC	Solar Community	UCL	MSSL	Space Weather Community	Space Plasma Community	Public	Space Agencies	Students	Solar Physicists	MSSL Eng Groups	Military	MPs	Local Government
Science	X	T			X	X						X		
Publicity	X	X	X											
Tech Transfer	X							X				T		
Training	X	X												
Kudos	T			X				T		X			T	T
Opportunities for Research		X			X	T		X	T	T		X		
Data Facilities to Use		X			T	X						X		
Teaching			X	X										
Money			X	T										
RAE			T	T										
Technology			X	X	X	X					X	X		
Instruments					X			T				X		
Excitement							T			X				
Interest							X							
Knowledge							X							
Entertainment							X							
National Pride							T						X	
Advanced Direction to Their Programmes								X						
Topics For Research									X					
Career									X	X				
Application of Physics									X					
Publications										X				
Opportunity to Influence the Bigger Picture														
Opportunity to Develop Novel Technology										X				
Challenges											T			
Jobs											T			
Taxes											X			X
Employment														X

The top stakeholder benefits are also indicated in table above as a T instead of an X.

Table 31 MSSL Solar Physics Group Stakeholder Analysis

Stakeholder	How to Influence Them	Constraints
PPARC	Membership of Panels Reputation Proposal	Money Approval
Local Government	Local Events Lobbying	Planning Permission
Solar Community	Providing Easy Access to Data Quality of Science Reputation/Track Record Collaborative Approach Personal Contacts	Willingness to Collaborate Competition in Science Domain
UCL	Quality/Volume of Science Head of Department Kudos Collaborative Approach	Money Staff Facilities/Infrastructure
MSSL	Quality of Science Research Assessment Exercise Income Opportunities for Technology Development	Teaching Load Resources
Space Agencies	Panel Membership Proposals Lobbying Reputation	Opportunities/Veto Technology Standards Time
Solar Physicists	Opportunity for Continued Research	Number of Cost of Living Effectiveness Area of Interest

Table 32 MSSL Solar Physics Group Influential Stakeholders

3. If their organisation is part of a larger group, what are their overarching requirements?

MSSL Solar Physics Group's context within University College London is depicted in Figure 111.

4. Given these constraints/requirements they needed to define a weighting scheme for the technology planning process.

Due to the time constraints this part of the exercise was not properly explored.

Solar Physics is nested within UCL as follows:

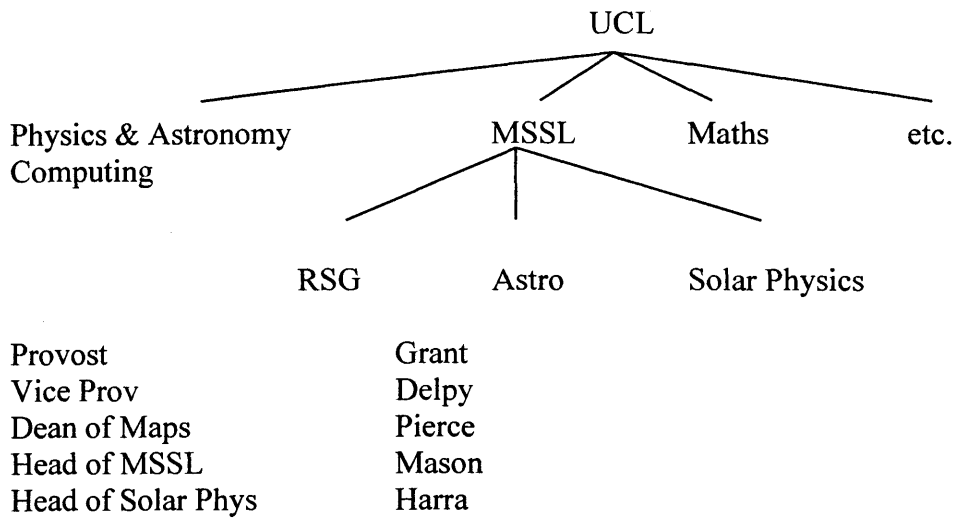


Figure 111 MSSL Solar Physics Group's Context Within University College London

7.3.5.2 Technology Drivers

1. Reviewing the customer needs (e.g. what are the key issues in Solar Physics that the group can address).

Science Objectives:

- To understanding how solar events affect the earth (interaction).
- To understanding the evolution of magnetic fields through the solar atmosphere.
- To understand how energy is released from the magnetic fields of the sun and other stellar systems.

Specific Objectives:

- To measure the corona field including in-situ local measurements between earth and sun.
- To co-ordinate current facilities including the identification of technology gaps which will need to be filled.
- To measure the full sun's spectrum (EUVX) (10km/s).

Alternative applications of any developed technologies:

- Fusion research (remote measuring of plasma).

2. Identifying the Key Product Features that will satisfy those needs (e.g. what would the group have to measure to answer such questions and what level would be competitive?).

The following technical capability was identified:

3D measurement of magnetic field of the sun requires the following technical features:

- Spatial resolution a few arc seconds as seen from Earth
- Magnetic field measurement accuracy - a few gauss
- Absolute measurement rather than comparative measurement of magnetic field
- Range of field strengths - a few to a few thousand gauss
- Location – over the line of sight between Earth and Sun
- Sample simultaneity – a few minutes (less than 1 minute within the Corona)

Plasma – velocity, density, temperature

- High spatial (as above), temporal (less 1 min) & spectral (10km/s) resolution over full Sun
- Able to identify different ion species
- Continuous long term measurement over solar cycle (22 years)
- Higher spatial resolution (100kms) for bullets 2 & 3
- Energy spectrum (radio to Gamma) for events.

3. Identifying Key Technologies (e.g. how the group will make the measurements?) – the issues.

The following key technologies were identified:

Full Sun Spectral Measurement

- Should the instrument be dispersive v non-dispersive?
- What should its wavelength range(s) be?

- Is a 'Super Moses' solution plausible? (Moses is a dispersive EUV technology presently being developed in the laboratory at MSSL).

Sun's Corona Measurement:

Current Techniques:

- Infra Red – has already been used.
- Xray – used in other contexts.
- EUV – not been used in this measurement and may have potential.
- Coronagraph – visual.

In Situ Measurement (i.e the measurement of particles and fields between Earth and Sun by direct measurement):

- Nano Satellites for space weather (recent research council call for proposals).
- Electron/Ion Detectors (a current strength of the laboratory).

Current Measurement Facilities:

- There are issues regarding the co-ordination of access to the facilities and use of the data gathered.
- Issues associated with the politics of the various existing facilities.

7.3.5.3 Review of How the Stakeholders Would Rate the Technology Solutions

This replaces the technology review. The review of how the stakeholders would rate the various technology solutions produced the following:

PPARC - value for money & kudos

Solar Community - mixed (will require careful work to gain acceptance within the community)

UCL - neutral+ (kudos, publications, money, etc)

MSSL - positive

Space Weather - positive

Space Plasma - positive

Public - neutral+

Space Agencies - positive (potentially needs to be carefully handled)

Students - neutral+

Solar Physics - positive

Engineering Groups @ MSSL - positive

Military - neutral

MPs - positive

Local Government - positive

7.3.5.4 Technology Plan

The outputs from the exercises of the second one-day workshop were used to generate the technology plan for MSSL's Solar Physics Group.

1. Mission Process: The following mission process was defined for the European Space Agency (ESA). However, there are quicker routes with some other space agencies (e.g. China, Russia, Japan).

ESA Route	Duration (yrs)
Get community consensus that this is the type of mission for the future	1
Influence ESA to select mission in next round	3
<u>ESA approve study</u>	
Conduct study	3
<u>Internal competition</u> (seek national funding in parallel)	1
<u>Selection</u>	
Announcement of opportunity (AO)	1
<u>Payload selection</u>	1
Development	4

Stages in underlined are key decision points. All key decision points involve the space agency as a key decision maker.

Additional notes from the exercise:

- Target influential individuals.
- Create and advertise a plausible mission.
- Be seen to be the main advocates and generate support.
- Japanese work differently - know repeat missions will come along.

- NASA and ESA work on similar model to each other.
- Get representation on working group by knowing when vacancies will come up.
- Bit like getting a product in the marketplace but more political.
- Perhaps more like getting an act through Parliament.

2. Key Stakeholders: The stakeholders from table 31 were ranked as shown in table 33.

	Stakeholder	Weight	Rank
1	PPARC	8	6
2	Solar Community	9	2
3	UCL	5	10
4	MSSL	9	2
5	Space Weather Community	7	8
6	Space Plasma Community	9	2
7	Public	7	8
8	Space Agencies	9	2
9	Students	3	12
10	MSSL Scientists	10	1
11	MSSL Eng Groups	8	6
12	Military	5	10
13	MPs	3	12
14	Local Government	2	14

Table 33 MSSL Solar Physics Group Key Stakeholders

3. Key Stakeholder Requirements: The key stakeholder requirements from table 31 were weighted as shown in table 34.

Stakeholder	MSSL Scientists	MSSL	Solar Community	Space Plasma Community	Space Agencies	MSSL Eng Groups	PPARC	Space Weather Community
Weight	10	9	9	9	9	8	8	7
Science	1	0.9	1	1	0.6	0.2	0.8	0.5
Publicity	0.5	0.6	0.6	0.6	0.9	0.5	0.8	0.3
Tech Transfer	0.1	0.7	0.1	0.1	0.8	0.7	0.6	0
Training	0.1	0.5	0.1	0.1	0.5	0.6	0.3	0
Kudos	0.5	0.6	0.5	0.5	1	0.6	0.9	0
Opportunities for Research	1	0.9	1	1	0.7	0.1	0.8	0.3
Data	1	0.8	1	1	0.7	0.1	0.8	1
Facilities to Use	1	0.8	1	1	0.7	0	0.6	0.7
Teaching	0.7	0.8	0.3	0.3	0.2	0.3	0.7	0
Money	0.8	0.9	0.8	0.8	0.9	0.9	1	1
RAE	1	1	0.8	0.8	0.1	0.2	0.7	0
Technology	0.3	0.7	0.3	0.3	0.8	0.9	0.6	0
Instruments	0.2	0.4	0.2	0.2	0.6	0.5	0.2	0
Excitement	0.5	0.5	0.5	0.5	0.6	0.5	0.4	0
Interest	0.8	0.6	0.8	0.8	0.7	0.8	0.2	0
National Pride	0.2	0.4	0.6	0.6	0.8	0.4	0.7	0
Advanced Direction to Their Programmes	0.2	0.3	0.5	0.5	0.7	0.3	0.7	0
Opportunity to Influence the Bigger Picture	0.7	0.7	0.7	0.7	0.7	0.5	0.7	0.3
Jobs	0.3	0.7	0.3	0.3	0.5	0.7	0.3	0.2

Table 34 MSSL Solar Physics Group Key Stakeholder Requirements

4. Technology Solutions: The workshop considered two options and generated the following list of observations/issues and an estimate of the associated costs for each option.

Option 1

- Evolution of solar orbiter with a scaling down of its capability.
- Four satellites would be required.
- Mass 300kg approx.
- Cost for 1st satellite £200m.
- Cost of programme £500m plus launches.
- Cost of Launches £200m.
- Larger operational cost.

Option 2

- Minimum payload
 - EUV imager (15kg approx).
 - Magnetograph (15kg approx).
 - Electron/Ion Analyser (2kg approx).
 - Magnetometer (1kg approx).
- Mass less than 100kg (to get a free ride on Ariane separation ring).
- Will require an additional motor if Ariane separation ring launch is selected since a transition from earth orbit will be necessary.
- Scientific payload mass (33kg).
- 3 to 1 payload to vehicle mass ratio.
- Requires 'Sciencecraft' / 'Faster, Better, Cheaper' approach.
- 6 satellites launched over a few years.
- Reduce redundancy to reduce mass.
- Telemetry will be an issue and so satellites will be required to have autonomy and make decisions about data to overcome telemetry issues.
- Cost for 1st satellite £25m.
- Cost of subsequent satellites £20m.
- Cost of programme £145m.
- Lower operational cost.

- Compared to option 1 it offers a better coverage of sun and better 3D view due to number of craft in orbit.

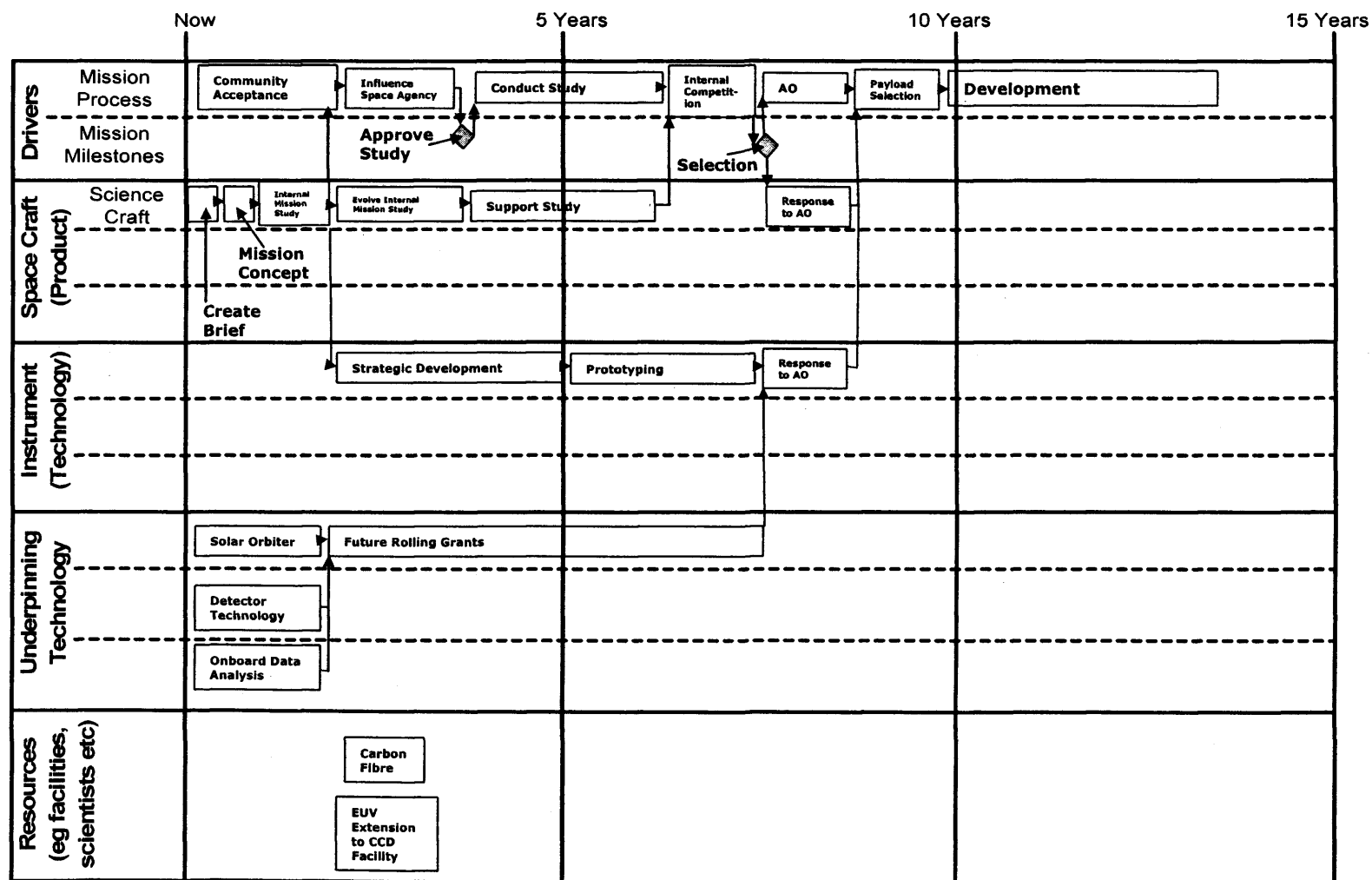
5. Rating of Technology Solutions: Tables 1 to 8 in appendix 10 show how each of the two options satisfies the key stakeholder requirements. Tables 9 to 12 in appendix 10 show the score by stakeholder, the score by option, an option summary and an overall summary respectively.

6. Technology Scenarios: The workshop briefly considered both options for all three scenarios. It was generally felt that option 2 would be slightly better for all three scenarios.

7. Technology Roadmap: As a result of comparing the two options against the stakeholder requirements and the technology scenarios, option 2 was selected to be charted on a technology roadmap, see Figure 112.

The output of the first one-day workshop was used by MSSL Solar Physics Group in a paper for future mission themes for the European Space Agency. The roadmap generated by the second workshop is to be used as the basis for future mission planning by the Solar Physics Group and the whole process is to be rolled out across all the science groups at MSSL.

Figure 112 MSSL Solar Physics Group's Technology Roadmap



7.3.6 MSSL Solar Physics Workshop Review – Lessons Learnt

The following issues were raised by the MSSL Workshops:

- A briefing note prior to the workshop would have helped the discussions by enabling some pre-thought and would have helped delegate buy-in to the process.
- Clearer terminology and a common language would have helped. The uses of the word ‘influence’ in two different contexts within the workshop lead to some confusion amongst the delegates.
- From the first one-day workshop the stakeholder analysis could have been clearer and linking to the rest of the workshop activities did not work as well as expected. Not keeping the outcomes from the stakeholder analysis in the back of the workshop mind meant that the workshop very quickly focused on the science and left the stakeholders’ needs hanging. A simpler list of stakeholder benefits would have been helpful and it would be useful to do this analysis using a spreadsheet that is projected onto a screen for all the audience to view. The workshop did not really address primary and secondary benefits. These issues were addressed in the second one-day workshop.
- Time needs to be spent early on bounding the problem.
- Time for the workshop is an issue due to the amount the workshop attempted to get through.
- For future workshops it would be helpful to have some background research to the problem/domain to aid facilitation of the exercises.
- The author had difficulty understanding the technology domain being discussed. The facilitation of the workshop was aided by Prof Alan Smith, who had the required domain knowledge. For future workshops, the organiser should either have the required domain knowledge or access to a friendly domain expert to help facilitate them and make sense of their outputs.

7.3.6.1 Questionnaire and Delegate Feedback

The questionnaire before and after the workshop proved inconclusive, see appendix 9.

7.4 Organisation 1 – Technology Planning Workshop

To address some of the issues raised by the MSSL workshop, a briefing note was sent to the delegates prior to the workshop, see appendix 11. In addition, background information regarding the problem to be explored by the workshop was sent to the author and his colleagues to aid the facilitation of the workshop. The format of organisation 1's technology planning workshop consisted of two half-days with the following objectives:

- To use parts of the technology planning model to address a specific issue – the quantitation of compounds synthesised in High Throughput Chemistry (HTC) and Microfluidics.
- To help the author validate the technology planning model, to assess its usefulness and identify areas of improvement.
- The aim of the first half day was to understand stakeholder needs, review context and constraints and generally to get to grips with the problem.
- The aim of the second half day was to evaluate potential solutions and identify good candidates to take forward to solve the problem.

To achieve these objectives the first part (Identification of Technology Drivers) of the Technology Planning and Management Lifecycle Model, Figure 106 on page 250, was adapted and used. The workshop focused only on the first part of this process as used in the MSSL workshop, shown in Figure 108 on page 253. However this workshop includes the use of TRIZ tool.

The TRIZ process for inventive problem solving used the systems approach to explore contradictions within the problem of the quantitation of compounds which prevent it from being “ideal”. This approach was adapted to this workshop as follows:

1. Identify the root cause of the problem within the existing system.
2. Explore the contradiction at the heart of the problem.
3. Explore the current system configuration for potential solutions.
4. Explore potential solutions for performance and cost improvements and cost of investment.
5. Evaluate, improve and prioritise solutions.

A stakeholder analysis was also added after the identification of the root cause of the problem.

7.4.1 Organisation 1 Workshop Outcomes

Using the adapted TRIZ process for organisation 1's workshop the following outcomes were achieved:

1. Identify the root cause of the problem within the existing system. The following problem was defined:

Problem Definition = To measure the absolute quantity and mass purity of a given substance within a given sample.

2. Explore the contradiction at the heart of the problem. The following key contradictions were identified:

- Common property – specific property (The measurement needs to be applicable to a wide range of compound properties but needs to provide quantity of a specific compound.).
- Calibration – no calibration (The measurement needs to be calibrated for each compound but as each compound is new there is no calibration information available.).
- Need response – Don't have response (This is similar to the calibration contradiction. The measurement requires information about the response of each compound but as each compound is new there is no response information available.).
- Structure – No structure (This is the contradiction of needing to know something about the structure of a wide range of new compounds to make the quantitation measurement and not having structural information available due to it being a new compound.).

3. Explore the current system configuration for potential solutions. The system configuration shown in Figure 113 was established.

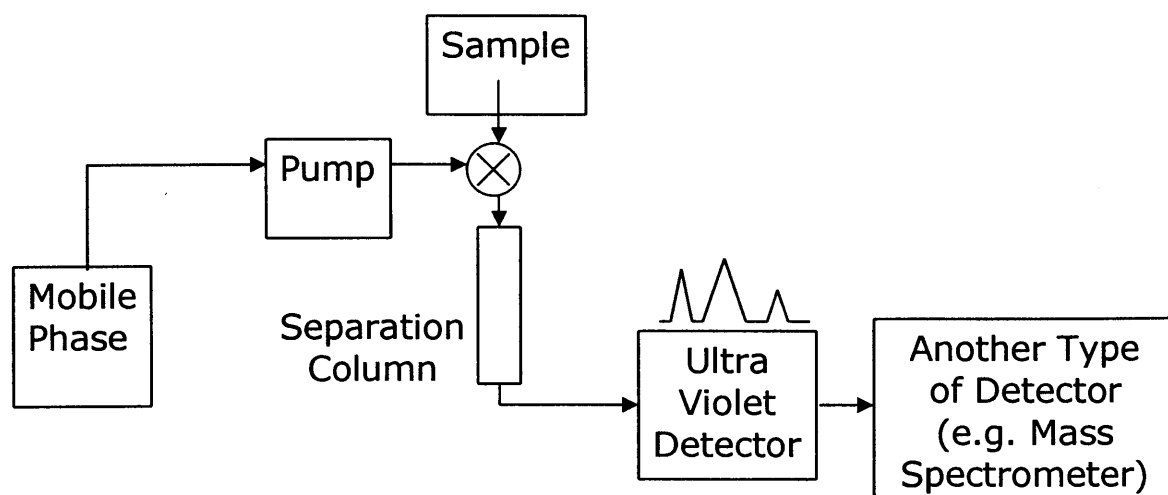


Figure 113 Current System Configuration

4. Explore potential solutions for performance and cost improvements and cost of investment. The workshop explored the potential solutions (see Table 35) to the problem and raised a few new radical options, for example, destroying a fraction of the sample to give a comparative measurement. The tool in Figure 114 was used to explore the potential solutions. (Note that some of the data has been removed at the request of organisation 1).

Technology	Comments
Gravimetric	<ul style="list-style-type: none"> + Automated, good throughput + standard, historic approach - sample size - measures bulk sample, not components
UV (Ultra violet)	<ul style="list-style-type: none"> + high throughput + in routine use for purity (LC-MS) - requires calibration standard per sample
** Prediction of UV response ** Indicates ideas added after first workshop	What is current state of UV spectra prediction – can we get a good-enough estimation of extinction coefficient from structure?
CLND Chemiluminescent nitrogen detection Http://www.antekhou.com/product/chrom/hplc.htm	<ul style="list-style-type: none"> + modest throughput + good quantitation of N content (atom counter) + can hyphenate with LC-MS - throughput & reliability of current instruments - compound must contain N - solvents must not contain N
** Linked UV-CLND	Ability to use first measurement of CLND to provide absolute mass and therefore calculate UV absorption coefficient. Further quantitative measurements can be obtained from just UV signal.
ELSD Evaporative light scattering detection	<ul style="list-style-type: none"> + high throughput + hyphenation with LC-MS commonplace - not suited or low molecular weight, volatile compounds - higher errors than ELSD
MS (Mass-spectrometry)	- requires calibration by sample
ICPMS (Inductively coupled plasma MS)	Widely used for trace element analysis
NMR Nuclear magnetic resonance spectrometry	<ul style="list-style-type: none"> + modest throughput + atom counting (H, F, P) + gives structural info at same time (primary purpose) - sample size (borderline) - data analysis not automated (especially mixtures)
AE Atomic emission	<ul style="list-style-type: none"> + potentially useful atom counter technology - currently applied to gas phase only - transfer to liquid phase a challenge – sensitivity of microwave plasma to mass burden.
** Any structure-independent methods?	Refractive index, vapour pressure, freezing point depression
** Miniaturise more conventional (e.g. combustion) CHN methods	How small could we go? How useful would results be?

Table 35 Potential Solutions For The Quantitation Of Chemical Compounds

Organisation 1: Solution Evaluation: HTC

MIN IDEAL IDEAL_Weight	Solution Attributes							Implementation Factors			
	Sample size (µmoles)	Accuracy	Selectivity Error	Maximum	Throughput (sample/day)	Process Time (mins)	Reproducibility	Cost (£)	Time to Develop (yrs)	Impact on Process Change	
				Acceptable Loss							
				(µmol)							
	5	20%	30%	1	300	5	70%	1000000	2	20%	
	16	5%	5%	0	1000	0.5	99.0%	0	0	0%	
	1	2	4	1.1	3	1.5	5	1	3	3	
Proposed Solution											
Gravimetric	16	13.5%	27.5%	0	1250	0.67	90.0%	0	0	0%	Overall Value
UV	16	500.0%	27.5%	0	300	1.00	99.0%	0	0	0%	55.20
CLND	16	10.0%	27.5%	0.005	300	1.00	90.0%	200000	1	0%	0.00
ELSD	16	200%	27.5%	0.005	300	1.00	90.0%	0	0	0%	20.39
MS	16	1000%	27.5%	0.005	300	1.00	72.5%	0	0	0%	0.00
ICPMS with tag	16	500%	27.5%	0.05	100	15.0	90.0%	500000	2	15%	0.00
NMR*	16	5%	5%	0.00	450	3.00	99.0%	1000000	2	10%	89.71
AED	16	10%	27.5%	0.005	300	1	95.0%	100000	1	0%	21.57
UV+destroy	16	10.0%	27.5%	1	300	1.00	99.0%	0	0	0%	20.35

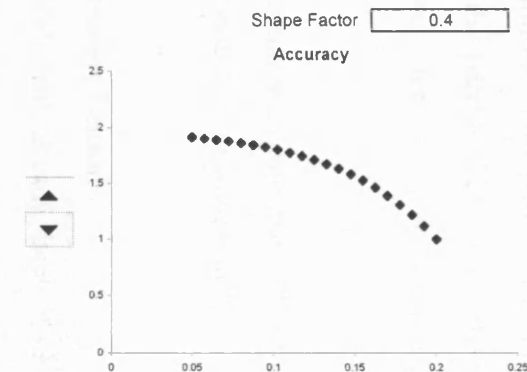
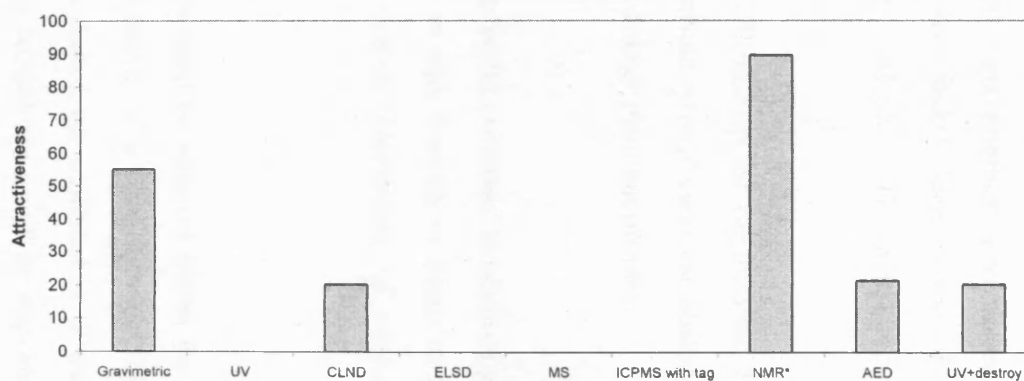


Figure 114 Organisation 1 Workshop – Technology Cost Benefit Analysis Model
(Based On Models Developed For The ISCAM Project By M. Fimes, D Cowper & A Smith)

5. Evaluate, improve and prioritise solutions. This part of the workshop was not completed due to the limited time. The aim of this part would be to use the model developed to identify candidate solutions (including a priority for each) and then to explore how these candidate solutions may be improved.

The workshop method and outcomes were summarised in a report which was circulated to the participants and interested individuals at organisation 1.

7.4.2 Organisation 1 Workshop Review – Lessons Learnt

The workshop addressed an issue which had already been well researched and considered by some of the participants. It was not surprising therefore that the optimal solution turned out to be the one currently in use – gravimetrics. Nevertheless, the workshop certainly facilitated discussions between different stakeholders, some of whom do not normally work together and generated a few good ideas. The workshop introduced the concepts of TRIZ to organisation 1.

The following issues were raised by the Workshop for organisation 1: buy-in to the technology planning process, establishing the ‘whole system’ view, establishing value, timing, definition of terms and generic vs. bespoke technology planning process.

7.4.2.1 Buy-in to the Technology Planning Process

Buy-in to the process is essential for a successful outcome. In addition getting the right number of people representing a wide range of stakeholders to input to the technology workshop will improve the quality of the output. Continuity of attendance between workshop elements is also important.

7.4.2.2 Establishing the ‘Whole System’ View

The value of different proposed solutions must be assessed within the context of the wider system/process, e.g. through a consideration of a systems view, identification of bottlenecks, inputs and outputs etc. In this workshop an appreciation of the wider system only emerged in part at a later stage. For future workshops it will be important to establish this at the onset. This ‘systems thinking’ up front needs to be carried out to scope the boundary of the problem and should also be linked to the stakeholder benefits generated from the stakeholder analysis.

7.4.2.3 Establishing Value

This issue is about establishing the weighted value in terms of the benefits. Within this workshop it was unclear where the solution added value. Establishing the value for the model is essential.

In future stakeholder analysis a set of generic categories needs to be established. These generic set of benefits would include things like:

- Throughput.
- Quantity.
- Programme (value etc).
- People/useability.

These categories can be binary or thresholds for example:

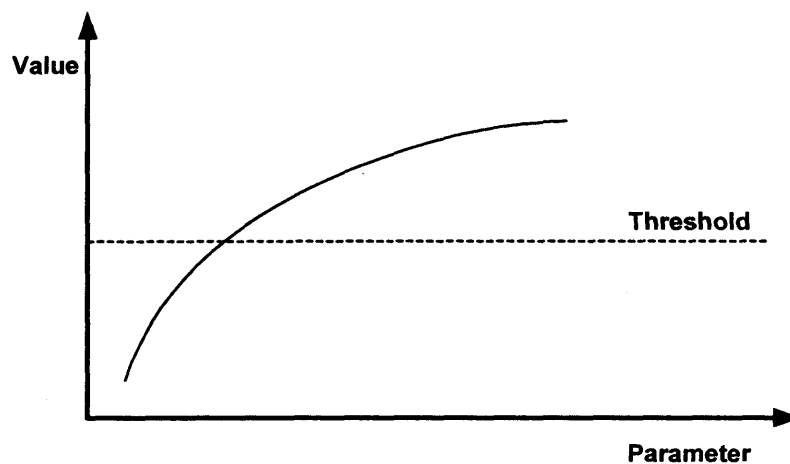


Figure 115 Parameter Performance vs Value Profile For Cost Benefit Analysis Tool

Figure 115 could be used with the list of selection criteria from organisation 1's study.

7.4.2.4 Timing

Timing is everything. This includes the duration allowed for the workshop to fully explore the issues and when the workshop is held in relation to the identification of the problem. In this case the problem being explored was not new and the discussions were limited to some extent by preconceived approaches from work already carried out.

7.4.2.5 Definition of Terms

There were many confused terms during the stakeholder analysis which mainly centred on the 'confidence' of the output of the measurement technique. It would be helpful to be clear on the use of the term 'confidence'. Confidence in the measured value depends on:

Accuracy – “the difference between the measured and true value of a quantity” (Wolf & Smith, 1990, p32-33).

Precision – “the repeatability of the measurement normally specified as a deviation of a reading from the mean (average) value” (Wolf & Smith, 1990, p32-33).

7.4.2.6 Generic vs. Bespoke Technology Planning Process

From both the MSSSL and organisation 1 workshops it has been established that the generic model requires customisation to meet the specific needs of the user/participating organisation. The workshop also needs to be communicated in the language of the user/participating organisation. From the results of these workshops, a template for technology planning within organisation 1 and a more generic template for broader application will need to be developed. However, it is acknowledged that this generic template will require some tailoring to meet the specific needs of the organisation conducting the workshop. It appears that one generic process does not suit all applications. It was also proposed to facilitate further technology planning workshops which included suppliers of instrumentation for organisation 1.

7.4.2.7 Questionnaire and Delegate Feedback

The questionnaire before and after the workshop proved inconclusive, see appendix 9. From the feedback questionnaire, overall the workshop was well received. However, there were not many new ground breaking ideas, see appendix 9 for analysis of the delegates' feedback questionnaire.

7.5 Organisation 2 And Precision Farming Alliance Technology Planning Workshop

The format of organisation 2's technology planning workshop consisted of a single day and had the following objectives:

- Explore who the Precision Farming Stakeholders are and what benefits a Precision Farming system would give each of them?
- Explore a model for a Precision Farming system including what combinations of technologies would be useful, what technologies are available and what the inputs and outputs (interfaces) between elements are.
- Explore what standards are required and which ones are already available.
- To use the output of the workshop to:
 1. Produce a guide that identifies how elements of a Precision Farming system fit together (which parts are already compatible and where new standards are required).
 2. Provide a blueprint for a farm business case.
 3. Provide a precision farming technology roadmap.

There were 34 people at the Precision Farming Alliance meeting on 30th Sep 04 held at Silsoe Research Institute, Wrest Park, Bedfordshire. The delegates ranged from a number of stakeholder groups:

Farmers	4
Equipment/Software supplier	12
Agronomists	10
Chemical Supplier	4
Retailer	1
University	3

To achieve these objectives the first part (Identification of Technology Drivers) of the Technology Planning and Management Lifecycle Model, Figure 106 and Figure 108, was adapted and used. The identification of the technology drivers was adapted as follows:

1. Reviewing the Customer needs (1. stakeholder analysis)
2. Identifying the Key Product Features that will satisfy those needs (2. precision farming system model attribute analysis, 3. precision farming system integration issues, 4. precision farming standards)
3. Identifying Key technologies (5. what technologies are missing?)

The stakeholder analysis was carried out by splitting the delegates into their stakeholder groups to:

1. Identify the general benefits they would look for in a precision farming system (e.g. make more money, save time)
2. Identify the attributes of a system that would deliver these benefits (e.g. increase yield/input, easy to use)
3. Weight these attributes in relative terms.

The exercise exploring the precision farming system model attributes involved providing six example systems ranging from very simple to highly complex, see Table 36. The workshop delegates were required to rate the system benefits and attributes using the scores from the stakeholder analysis.

System 1	Yield mapping for information only.
System 2	Yield mapping and using the information to make management decisions concerning cultivations, seed rates and fencing.
System 3	Yield mapping, weed/disease/crop canopy mapping and targeted pesticide application.
System 4	Yield mapping, weed/disease/crop canopy mapping and targeted fertiliser application.
System 5	Yield mapping, soil analysis and targeted fertiliser application.
System 6	Full precision farming implementation.

Table 36 Precision Farming Example Systems

The precision farming system integration issues, precision farming standards and identifying key technologies (what technologies are missing?) were carried out as facilitated group discussions.

Organisation 2's workshop was developed addressing the issues raised by the previous workshops as follows:

Buy-in to the Technology Planning Process: To address the issue of managing the delegates' expectations, a briefing note was sent to the delegates prior to the workshop, see appendix 12.

Establishing the 'Whole System' View: The second exercise of the workshop was designed to explore different views of what a whole precision farming system looked like and how these views compared to the benefits to the various precision farming stakeholders.

Establishing Value: The stakeholder analysis' aim was to establish the value of each benefit of a precision farming system. The outcome of this exercise was taken further to develop a template for a business model for a precision farming system.

Timing: This again was critical, especially given the workshop was being hosted by the Precision Farming Alliance, and during the workshop strict adherence to the timetable was required to ensure that all the aspects of the workshop were addressed.

Definition of Terms: The audience of the workshop was particularly sensitive to jargon and inconsistent terms. This sensitivity was expressed by the organisers of the Precision Farming Alliance. Great care was taken to present the workshop in the language of the delegates and included a review of the workshop material with organisation 2's sponsor and representatives from Silsoe Research Institute.

Generic vs Bespoke Technology Planning Process: The process (described previously) was tailored to meet the needs of the target audience (as described above).

Questionnaire and Delegate Feedback: Due to the feedback from both the MSSSL and organisation 1 workshop and the anticipate target audience it was decided to drop the questionnaire for the precision farming workshop.

7.5.1 Organisation 2 And Precision Farming Alliance Workshop Outcomes

7.5.1.1 Reviewing Customer Needs - Stakeholder Analysis

Figure A12 – 1 in appendix 12 shows the results of the stakeholder analysis. Each stakeholder group listed a set of benefits and attributes and weighted these attributes in relative terms.

7.5.1.2 Identifying Key Product Features - Precision Farming System Model Attribute Analysis

Each stakeholder group used its list of weighted attributes to assess each of the six example precision farming systems given, see Figure A12 – 1 in appendix 12. The following observations were made:

- Farmers couldn't see the point in System 1 and therefore gave it very low scores across the board.
- Farmers were sceptical about the ability of Systems 3-6 to work in practice, given difficulties they had had with compatibility, reliability etc. of simpler systems.
- Equipment suppliers felt that much of the specialist equipment was difficult for farmers to use and that software and hardware standards might be the problem.
- Agronomists were sceptical that System 5 with variable N could work in practice, but rated System 5 with variable P and K very highly.
- Chemical suppliers argued that System 5 with variable N could work.
- Retailers favoured sophisticated systems that could offer traceability of inputs, and were less concerned with ease of operating and compatibility issues.
- Universities identified the 'Farmer' as an important attribute (and gave it a weighting of 4). This means that universities are interested in those attributes identified by farmers as important, as this drives uptake of precision farming. The three most important attributes to farmers were therefore added to the universities' attribute list, together with the farmers' scores for the systems. The farmers' most important attribute (cost effective) was given a weighting of 4, and the other attributes were reduced in proportion to the farmers' weightings. Reliability therefore became $4 \times 4/5 = 3.2$.
- Since Universities identify 'Cost Effective' as being important because it determines uptake, this is effectively the same as the [Farmer] Cost Effective attribute. In this case, the attribute with the higher weighting was chosen.
- If the weightings are the same (as in this case), preference is given to the stakeholder's rating. If the attributes are duplicated for different reasons, then both the ratings are counted as normal.

7.5.1.3 Identifying Key Product Features - Precision Farming System Integration Issues

The group discussion on the issues encountered in integrating a precision farming system identified the following issues:

- Contradictory statements regarding hardware compatibility.
- Software compatibility – needs to be seamless.
- PF requires operators to have Information Technology skills.
- Programs are becoming more intuitive.
- Time constraints on collecting and processing data from the PF system.
- Manual overrides are required – when all else fails the farmer can still get on with his business.
- 24 hour/7 days a week access to support.
- Robust interfaces/process – varies the level of operator training.
- Inputs vs actual application – feedback of application data (what has actually been applied).
- Not yet 100% reliable.
- Lack of university underpinning research – issue for government and the research councils.
- ISOBus – progressing well with ISO taking ownership of the standard (ISO11873 – both a hardware and software communications protocol) widely available – most of the manufacturers have bought into it.
- Technology exceeds agronomic understanding (may be PFA could help by providing support to new farmers – however not currently part of its terms of reference).
- Independent advisors – the HGCA does some of this.
- Reasons for no business case:
 1. Viewed as merely high tech (over ‘sexed’).
 2. Value of environmental gains unclear.
 3. CAP – not an imperative.
 4. Incremental change / PF not specific (means different things to different people).
 5. Multitude of technology.

- 6. Fragmentation.
- 7. No generic case.
- Legislation drives change.
- Can PF position in the market place.
- International dimension.
- Uniform quality for easier processing – expensive to monitor.
- Better relationship between processing and farmer regarding quality.
- Commodities vs fresh produce.
- Gives opportunity to secure market.
- Traceability needed for on-selling by food processors and packers.
- Trust with retailers.

7.5.1.4 Identifying Key Product Features - Precision Farming Standards

The group discussion on precision farming standards identified the following issues:

- KISS – Keep It Simple Stupid
- Standards have improved over the last 5 years and are not such an issue now.
- Useability.

Interestingly, the issue of standards was a common theme during the study. However, the group dismissed issues with standards as being much improved, see second issue above.

7.5.1.5 Identifying Key Technologies – What Technologies Are Missing?

The group discussion on what technologies are missing in precision farming only identified the following:

- Missing sensors – not complete.
- Direct injection for sprayers that works.
- Identification of weed/chemical application.
- Variable application benefits.

During the study it was identified that there was a lot of technology push in precision farming, therefore it is not surprising that the workshop indicated that there are no large

technology gaps. There is a feeling that the PF Community have all the technology they need and that just the issues identified above need addressing to deliver satisfactory capability from PF equipment. Any technology roadmap should be about how to achieve better uptake in precision farming by utilising what is already available and addressing the issues above. Technology roadmaps for future technologies should then address how to take precision farming to a higher plane.

7.5.1.6 Precision Farming Roadmap

The aim of the precision farming roadmap is to address the barriers that are preventing a wider adoption of precision farming. The precision farming roadmap is shown in Figure 116 and is split into three categories: i) the Business Case, ii) the Enablers and, iii) the Technology. The business case is the main driver regarding the value of precision farming and its subsequent adoption. The enablers affect the business case for precision farming and, with the exception of the External Factors, will be under the control of the Precision Farming Community. The technology areas identified support the enablers and hence the business case for precision farming.

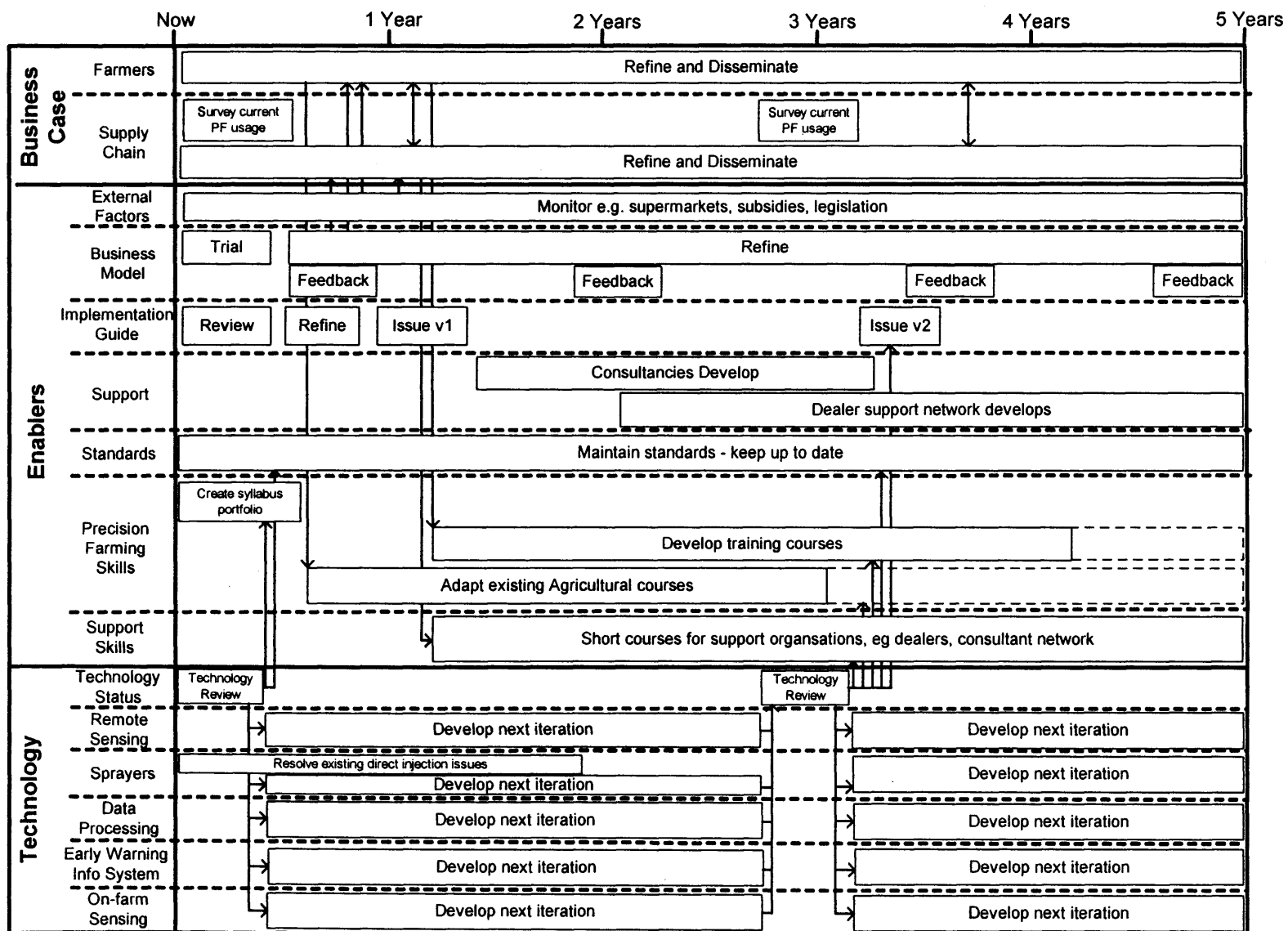


Figure 116 Precision Farming Roadmap

7.5.1.6.1 The Business Case

The business case is split into two categories: i) the case for Farmers and, ii) the case for the rest of the supply chain.

The business case for the farmers is important as it governs the uptake of precision farming. The business case is shown as a continuous bar being constantly refined and disseminated. The constant refinement is required to ensure actual results and best practices are captured for future reference. This refinement is an activity that UCL could fulfil on behalf of the precision farming community. The dissemination of the business case is important to ensure the farming community is aware of the benefits that precision farming can bring to their farms. The dissemination activity is one that could be fulfilled by the Precision Farming Alliance.

The business case for the precision farming supply chain is also important as there needs to be a market demand for the products and services in order for the supply chain to invest in new developments. This investment needs to be carried out in a timely manner in order for the 'right' products and services to be available to the farmers when they need it. Therefore keeping the supply chain well informed of future requirements is essential for the supply chain's investment to be successful. Part of keeping the supply chain well informed will be the dissemination of the business case. Again the refinement activity of the business case could be carried out by University College London and the dissemination could be carried out by the Precision Farming Alliance.

7.5.1.6.2 The Enablers

The enablers affect the business cases for both the farmers and the supply chain. It consists of: external factors, a business model and a series of implementation activities (implementation guide, support (advice) to the farmer, standards, and the development of precision farming skills).

7.5.1.6.2.1 External Factors

The external factors category covers all the influences that are beyond the control of the Precision Farming Community which will directly affect the business case for precision farming. For example, a change in legislation, a change in subsidies, or a demand from supermarkets that makes traceability a mandatory requirement will affect the need for

precision farming and hence the business case. These external factors will require continuous monitoring to identify how they influence the business case. This monitoring activity could be carried out by the Precision Farming Alliance.

7.5.1.6.2.2 Business Model

The business model is the model developed by University College London as a result of the one-day technology planning workshop with the Precision Farming Alliance held at Silsoe Research Institute, Silsoe, Bedfordshire, on the 30th September 2004. The model requires trialling on a sample of farms that are already using precision farming. The results of the trials will be used to refine the model. A continuous process of refinement is proposed using feedback at regular intervals from the users of the model (farmers). The refinement of the model could be carried out by University College London.

7.5.1.6.2.3 Implementation Guide

The precision farming implementation guide has been produced by University College London again as a result of the one-day technology planning workshop. This guide aims to provide the farming community with advice for the implementation of precision farming. This guide needs to be reviewed and refined before being issued as version 1. An update to the guide is proposed to coincide with the latest developments in precision farming technology. The refining and issuing of the precision farming guide will be carried out by University College London.

7.5.1.6.2.4 Support

Support is very important to farmers, therefore a support infrastructure for precision farming is required. This support infrastructure will consist of consultancies to provide advice on the type of precision farming system required and the integration of the system elements and a dealer network for the supply and maintenance of the equipment/software. The development of the support infrastructure will be driven by market demand and hence the business case for the supply chain will be required to stimulate this demand. Timing for the supply and demand of support will be an issue to ensure that the infrastructure is in place when the farmers need it. The roadmap currently shows the development of this infrastructure starting in the future (approximately 1 year) to allow the business case for precision farming to be established before the supply chain commits to the investment.

7.5.1.6.2.5 Standards

A continuous bar is depicted on the roadmap for the maintenance of precision farming standards. Keeping the standards up to date is important to ensure that the issues of equipment/software compatibility and integration are avoided. The maintenance of the precision farming standards could be a role performed by the Precision Farming Alliance.

7.5.1.6.2.6 Precision Farming And Support Skills

Training in precision farming is an issue that needs to be addressed. The roadmap identifies the need to create a training syllabus portfolio for precision farming and that this syllabus will need to be incorporated into existing agricultural courses (for farmers, agronomists, etc.) and into new courses. There is also a requirement to provide training courses for the support organisations, for example the dealer and consultant networks. The dotted boxes on the “develop training courses” and “adapt existing agricultural courses” indicate continuous development of existing courses and the development of new courses.

University College London can facilitate the creation of the training syllabus portfolio in conjunction with the various agricultural colleges and training providers.

7.5.1.6.3 The Technology

The technology section of the roadmap is a general outline of the technology areas requiring iterative development, with the exception of the specific issue of resolving the problems of existing direct injection sprayers. These areas include: remote sensing, sprayers, data processing, early warning information systems and on-farm sensing. Details of these developments will need to be addressed by the suppliers of the technology.

Prior to each iteration of technology developments there is a technology review to establish the current landscape. The outcome of this review informs: the next development cycle, the maintenance of the standards, the development of new and adaptation of existing training courses, and the update to the implementation guide. This review could be carried out by University College London.

7.5.2 Organisation 2 And Precision Farming Alliance Workshop Review – Lessons

Learnt

The following issues were raised by the Workshop for organisation 2:

- Organisation 2 believed that some good points were raised, some useful information came out of the workshop and that it was a good thing to do for the precision farming community.
- The workshop could have pushed the delegates harder in their syndicate groups when carrying out the exercises. Delegates tended to talk around the subject being discussed and therefore required focusing in order to make the best use of the time available.
- Related to the observation above, time was again an issue. There was a lot of ground to cover during the workshop and getting through it in the time available was a challenge. The amount of time required for effective technology planning may be a contributing factor as to why level of this activity was so low in the organisations interviewed during the study detailed in chapter 3. Time pressures in organisations usually mean that activities like technology planning get pushed aside over more critical immediate issues.
- The workshop required the facilitator to be flexible and to think on one's feet to avoid losing the audience. At several points the workshop required steering back on course.
- A balance is required between breaking into syndicate groups and whole group discussions. Syndicate groups avoid the pitfalls of the large group being dominated by a few and therefore valid points of view being missed (described in the section on committees of experts in chapter 2). However, the delegates may lose their way when in small groups without guidance and syndicate groups waste valuable time when they break away and regroup for each exercise.

7.6 Field Trials Conclusions

The following conclusions were drawn from the three field trials conducted.

7.6.1 Buy-In To Technology Planning Process

Buy-in to the technology planning process is important to ensure that the audience is bought into the process and are actively contributing to the activities. This can be achieved by:

- Providing a briefing note to ensure the delegates are prepared for the workshop.
- Ensure that the delegates know the value of the activity. If delegates do not see the value of the activity they will come with the wrong attitude or may not attend at all. Either situation will undermine the technology planning activity.
- The workshop facilitator needs to be flexible to avoid losing the delegates and to adjust the workshop to cater for unexpected outcomes.
- The workshop facilitator needs to prepare for the workshop – including understanding the technology issues being explored.

Workshops are an opportunity to motivate groups to support a common technology plan. The author believes this worked particularly well for the precision farming alliance workshop.

7.6.2 Establishing Whole System View

Establishing a whole system view is required to ensure the outcomes of the technology planning process actually add value. Some things to consider are:

- Appreciation of the wider system – where are the bottlenecks, etc?
- Use systems thinking up front to bound the problem being addressed.
- Use stakeholder analysis to explore the system and the problem from other view points.
- Ensure benefits gained can be traced back to the stakeholders' requirements.

7.6.3 Establishing Value

Establishing value is important to establish the value of technology planning. This value will vary depending on the level within the organisation. The use of metrics can give some idea of effectiveness. These metrics can be used to identify:

1. Does technology planning prevent you investing in a technology?
2. Does technology planning generate new insights, a pool of ideas, an increase in the number of new ideas generated or better informed staff?
3. The learning behind the exercise of technology planning – process knowledge rather than the output of the process.
4. Apply metrics to outputs – does it improve decisions – do we have more successful technologies and fewer failed ones?

It is also important to establish value in terms of the benefits to stakeholders.

7.6.4 Timing

The timing of technology planning is important in terms of when things occur and how long they take (the balance between pushing participants too hard or not covering the required ground). There are conflicts associated between the duration of the technology planning lifecycle and the lifecycle of products/services, technology development and maturity of problems. These conflicts need to be considered during the technology planning and management lifecycle.

7.6.5 Definition Of Terms

To avoid losing participants in the technology planning and management process, a clear common language needs to be used both in terms of the process and the technology problem being addressed.

7.6.6 Generic Vs Bespoke Technology Planning Process

It is clear from the field trials that a generic model requires tailoring to each situation when it is used. This tailoring includes addressing some of the other observations above. For example, the process requires tailoring in order to ensure a clear common language is used and that the facilitator understands the context in which the process is being used.

7.6.7 Opportunistic Element

Technology workshops need to be responsive and opportunistic to spot possibilities outside of its strict objectives. The workshop facilitator needs to have a proactive attitude yet responsive to the climate of the day.

7.6.8 Technology Domain Expert

The author had difficulty understanding the domain of the technology being discussed. The facilitation of the workshop was aided by Prof Alan Smith, who had the required domain knowledge. For future workshops, the organiser should either have the required domain knowledge or access to a friendly domain expert to help make sense of their outputs.

7.6.9 Technology Roadmaps

The following observations were made regarding the use of technology roadmaps:

- Roadmaps need to be more than just technology maps
- Roadmaps need to chart where one wants to be and how to get there and should include:
 - Drivers
 - Business case (from different perspectives) of why you need to get to where you want to be
 - External Factors & Monitoring
 - Enablers
 - Political, buy-in, expectation management (higher management)
 - Skills, training, support systems
 - Credibility, ownership, responsibilities.
 - Technology
 - Capability survey
 - Technologies
 - Standards
 - Implementation strategy
 - Expectation management (user).

The following chapter (8) describes taking the model forward to provide a package that can be easily implemented within organisations.

Chapter 8

8. TECHNOLOGY PLANNING AND MANAGEMENT LIFECYCLE MODEL IMPLEMENTATION

8.1 Introduction

This chapter proposes to take the model forward to provide a package that can be easily implemented within organisations. The aim is to provide a toolbox of technology planning tools along with guidance on the tool card of when, where and how to use them. The aim of this toolbox is to teach an organisation how to plan and manage technology so that they can do it for themselves rather than relying on an external organisation to help them.

8.2 Tool Box Approach

The toolbox is structured (as shown in Table 37) into 3 layers:

- i. Top-level lifecycle process
- ii. The 5 sub-processes of the lifecycle
- iii. The individual tools used by the 5 sub-processes.

The top level lifecycle process, the 5 sub-processes and each of the individual tools have been detailed on a single side of A4 paper; see Figure 117 for an example. The approach is to make each of the tools in a presentable format that is simple and easy to use. The aim is to make the tools accessible and avoid the user having to wade through large volumes of information in order to use them. This should also overcome the issue of individuals and organisations not being aware of the existence of these tools. Being a single side of A4 paper means that each tool can be turned into a laminated card that can be used for reference during use. Alternatively, the tools can be electronically hyper-linked together either on CD ROM or on an organisation's intranet.

Each tool description contains the title of the tool (the What), its purpose (the Why), the part of the lifecycle in which it is used (the When), details of the process in diagrammatic and text format (the How), whether the tool is to be used internally or externally (the Where),

the roles and responsibilities of participants (the Who), and finally any additional notes for supporting information, see example Figure 117. The complete range of tools can be found in appendix 13.

The Technology Planning and Management Lifecycle Model's aim is to provide a high level framework to structure an organisation's technology development. This top-level framework will allow organisations to pick and mix the lower level individual tools as appropriate to their needs and at the right time during the planning and management process.

Technology Planning & Management Lifecycle Process	
Sub-Process	Individual Tool
Develop Technology Drivers	Attribute Analysis
	Footprinting
	Morphological Analysis
	Needs Research
	Relevance Trees
	TRIZ
Carry Out Technology Review	Audit
	Competitor Capability
	Delphi
	Footprinting
	Nominal Group
	Technology Maturity Assessment (containing Technology Readiness Levels and Trend Models (S Curve))
	Technology Monitoring (Sources Of Capability)
Produce Technology Plan	Decision Making Tools
	Roadmaps
	Technology Games
	Technology Scenarios
Implementation	Invest In Existing Technology
	Develop New Technology
	Dispose Of Existing Technology
Implementation Monitoring	Audit
	Benchmarking
	Review Competitor Capability

Table 37 Technology Planning And Management Tool Box Structure

Title..... (What)	
Purpose/Aim of Tool: (Why) To review	When to use: (When) Identifies which part of the lifecycle it addresses
Process: (How) [uses internal/external resources] (Where)	
<pre> graph LR Start(()) --> Step1([Simplified UML Activity Diagram]) Step1 --> Step2([To Diagramitically Show The Process Of The Tool]) Step2 --> End(()) </pre>	
Process Steps: (How)	
1. The 2. Collate..... 3. Review..... 4. Etc.	
Additional Notes: Useful supporting information.	Roles & Responsibilities (Who) Process Owner: Senior Management Participants: Individuals from the business and from external organisations
(c) University College London	

Figure 117 Technology Planning And Management Tool Card Example

8.3 Technology Planning and Management Toolkit

The following sections briefly describe some implementation and tailoring issues for each of the tools. The complete range of one-page tool cards can be found in appendix 13. The complete range of these tool cards has not been fully used and it is expected that additional issues may be raised during use and that they will need refining as a result. Complete tailoring will be required by the organisation implementing the tools as this will depend upon application and will require some trial and error.

8.3.1 Technology Planning and Management Lifecycle Top-Level Process

The top-level generic technology planning and management lifecycle process should fit well with most senior management activities (based on the author's own experiences). Any existing management process should be adapted to include the aspects covered by technology planning so that technology planning and management can be seamlessly introduced into existing company frameworks. Existing management practices will already generate the inputs to the technology planning and management process (e.g. marketing) and outputs from the technology planning and management process will inform senior management in their decision making.

8.3.1.1 Develop Technology Drivers Sub-Process

The first part of this sub-process (solution objectives, technology capabilities, & technology solutions) is very important for establishing the parameters by which value will be judged. This establishing of value is crucial in the decision making process and any long-term measures of effectiveness.

By creating and communicating a vision and creating an environment and culture for technology planning, senior management can demonstrate their commitment to the process. The changing of the organisation's culture will take a long time before it becomes "the way we do things around here". Part of this culture change will require a common consistent language to be used and a clear definition of terms so that everyone in the organisation understands each other and understands where and how they fit into the process.

In the same way as the top-level lifecycle process should be incorporated into the organisation's planning cycle, this process needs to be included so that it forms an integral part rather than a 'bolt-on' extra.

8.3.1.1.1 Attribute Analysis Tool

In a similar context to needs research (see below), part of this tool's process may already be used in the organisation. Parts of the tool can also be used in conjunction with other tools. For example, it can be used with the needs research tool when eliciting customer needs or with morphological analysis tool when reviewing key product features or key technologies.

8.3.1.1.2 Footprinting Tool

This tool may be used as a stand alone tool or parts of it used in conjunction with other tools. For example, the classification of competitive impact and position and the associated matrix can be used when reviewing technology maturity with the technology maturity assessment tools (technology trend – S curve and technology readiness levels) or in conjunction with TRIZ when identifying key technologies.

8.3.1.1.3 Morphological Analysis Tool

The main tailoring required for this approach is the level of the system configuration analysed by the organisation. This will depend upon the organisation's position within the supply chain. For example, system integrators will be concerned about system and sub-system capability rather than components. Again this tool can be used in conjunction with other tools (e.g. the relevance tree tool).

8.3.1.1.4 Relevance Tree Tool

The tailoring of this tool is similar to the morphological analysis tool and involves determining to what level of the system configuration is the organisation interested in analysing.

8.3.1.1.5 Needs Research Tool

The process of capturing customer/market needs will already be present in the organisation through their marketing and product development activities. The customer/market needs should then be fed into the technology planning process.

8.3.1.1.6 TRIZ Tool

The TRIZ tool will typically take the form of a one-day workshop to address a specific problem. The participants should include "experts" in the field of the problem, users of the system where the problem lies, and some suitable delegates not close to the system or the

problem to act as ‘devils advocates’ and present some new ideas. The workshop needs to be facilitated and this person should have an understanding of the problem domain (to keep the workshop on track) and be flexible to avoid losing the delegates. For example, if syndicate group work for the exercises fails to deliver the required outcomes, then the exercises might need to be reconfigured as a group discussion. The facilitator also needs to be careful regarding terminology associated with the TRIZ tool. For example, “determining the system of interest’s configuration” and “exploring the contradiction at the heart of the problem”. These terms will need translating into something the audience will understand.

8.3.1.2 Technology Review Sub-Process

Again this process needs to be incorporated into the organisation’s management planning cycle. However, most of the activity in this phase will be carried out by individuals within the organisation’s functions or by funded external organisations. How these activities are incorporated into these organisational functions will be dependent on the structure of the organisation. This phase requires management commitment, as substantial resources will be required.

The use of both the initial review and follow up review of technology tools will be at the discretion of the organisation. Both techniques can be interchanged (allowing for the advantages and disadvantages of each, see chapter 2 or appendix 1).

8.3.1.2.1 Auditing Tool

The difficult part of the technology audit is to find the right individuals to carry out the audit. The auditors may be internal or external to the organisation. Both approaches will have advantages and disadvantages that need to be considered. For example, employees may not be comfortable providing an external auditor with the information required. Conversely employees may feel threatened by an internal auditor and may withhold information. It may be possible to identify the right experts during the review of sources of expertise.

8.3.1.2.2 Competitor Capability Review Tool

This tool proposes a number of methods for obtaining competitor’s technology capability information all of which will require tailoring to the specific situation. Also there is flexibility as to which of the proposed activities the organisation selects. For example, hiring key staff from the competition is an extreme way of obtaining information and high risk (e.g.

the staff may not wish to move, or additional staff cost will need to be borne by the organisation). In some cases the competition may wish to collaborate on technology development and therefore make information available.

8.3.1.2.3 Delphi Tool

The main implementation issues associated with this tool are the selection and participation of the panel of experts, and the number of iterations regarding the invitation to reconsider responses. Getting all the experts to respond to the questionnaire in a timely manner will need to be carefully managed. The tailoring of this tool centres on the questionnaire, as this needs to be carefully designed to ensure the right information is gathered whilst keeping the amount of bias introduced to a minimum. The organisation can decide whether it needs to carry out such an exercise, especially if it is intending to carry out a nominal group exercise.

8.3.1.2.4 Nominal Group Tool

The main implementation issues with the nominal group tool are identifying and gathering all the experts together in the same room, and the control and influence the group leader has on this panel of experts. Again the organisation can decide whether it needs to carry out such an exercise especially if it is intending to carry out a Delphi exercise.

8.3.1.2.5 Technology Maturity Assessment

This tool uses the technology trend model (S curve) to assess the rate of change of technology, footprinting (covered by a separate tool card) to assess the competitive impact and position, and the technology maturity levels (TRLs) to assess the readiness of the technology to be incorporated into the organisation's products/services. The example of TRLs listed in the tool cards are based on the ones used by NASA. These levels will need to be tailored by the user organisation to suit the industry, type of product/service the organisation deals with.

8.3.1.2.6 Technology Monitoring (Review Of Sources Of Technology Capability)

The amount of technology monitoring required/performed will be dependent upon the amount of technology required by the organisation, and the amount of resources available to the organisation. This process will need to be highly tailored to suit the organisation.

8.3.1.3 Produce Technology Plan Sub-Process

During this part of the technology planning and management lifecycle the use of scenarios and/or technology games is discretionary and will depend upon the application. The use of roadmaps again will depend upon application.

The use of a decision making tool can be something adapted from an existing organisational tool or a new bespoke one for the particular application. The author found it beneficial to generate specific decision making tools using a Microsoft ExcelTM spreadsheet.

Any technology plan will need to chart activities, required investment, and expected technology maturity levels against milestones. The plan is an important document, as it will be used to take the organisation forward and be used to monitor progress. Therefore, the plan should be a “living document” for reference by all technology development activities and be in a form that is easily accessible and easy to interpret by the organisation.

8.3.1.3.1 Decision Making Tools

Most organisations will have existing decision-making processes/forums that can be adapted to include technology planning and investment decisions. The organisation may also have decision-making tools that can be adapted. If existing tools are unavailable it is fairly straightforward to develop a tool using spreadsheet software. The user can make this tool as simple or as complicated as they wish.

8.3.1.3.2 Roadmapping Tool

The roadmapping process has been reduced by the earlier stages of the Technology Planning and Management Lifecycle Model. The roadmapping process is a charting exercise (typically in the form of an internal workshop) using the information generated by the earlier parts of the process. A typical workshop format is shown in the tool card, see appendix 13. This format can be tailored to suit the organisation implementing the workshop in terms of time, availability of participants, etc.

8.3.1.3.3 Technology Game Tool

The use of the technology game is similar to the technology scenario. The game may involve using software simulations (either off-the-shelf or bespoke) and will require a level of investment. In the early stages of the Technology Planning and Management Lifecycle

(during ‘identify technology drivers’) the use of such tools should be considered and the appropriate investment made.

8.3.1.3.4 Technology Scenarios Tool

The use of scenarios can be by a few individuals reviewing data presented in the technology forecast or by a more formal workshop. Both of these implementations will usually be internal to the organisation.

8.3.1.4 Implement And Monitor Technology Plan Sub-Processes

These sub-processes will require extensive tailoring to meet the needs of the organisation implementing the Technology Planning and Management Lifecycle. This part of the model has not been explored during the field trials and therefore, tailoring advice is limited. Refinement of this part of the model is recommended for further work.

8.3.1.4.1 Benchmarking Tool

The difficult parts of implementing the benchmarking process are the identification of the appropriate metrics, the identification of the right organisations to compare against (e.g. a hospital could compare some of its patient care to hotels) and obtaining the desired data as some organisations will be reluctant to release this data as it gives them a competitive advantage.

8.3.1.4.2 Exploit Existing Technology

The main area of customisation for the exploitation of existing technology is in the review of organisation’s structure, skills and the facilities and equipment. These three characteristics of the organisation are interrelated and will vary significantly from organisation to organisation. They will also be affected by the approach adopted for the particular technology. For example, if development is to be outsourced this will reduce the amount of internal skills, equipment and facilities required for development and the main focus will be how to bring the technology into the organisation’s product stream.

8.3.1.4.3 Introduce New Technology Tool

The tailoring of the introduction of new technology is similar to the ‘exploiting existing technology’ tool described previously. If the introduction of a new technology is to replace an existing technology then the two activities will need to be co-ordinated in order to avoid

any mismatches in development/introduction and the disposal activity timescales leading to a technology gap for the organisation.

8.3.1.4.4 Dispose Of Technology Tool

Again the tailoring of this activity will depend greatly on the organisation as previously discussed.

8.4 Further Work

The Technology Planning and Management Lifecycle Model tool box outlined in this chapter aims to provide a package that can be easily implemented within organisations. The approach proposed is untested and will therefore require testing by trying out the tool box within organisations. The tool box will require refining to address any issues raised through its implementation.

The final chapter provides conclusions, explores the dissemination and further work generated from this thesis.

9. CONCLUSIONS AND FURTHER WORK

9.1 Conclusion

This PhD thesis set out to establish the “when”, “where” and “how” of technology planning and management. A review and modelling of existing tools and techniques established some of the “how” of technology planning and management and identified some gaps. The most significant of these gaps is a lack of a “lifecycle” framework for technology planning and management that will allow an organisation to know when and where to use the appropriate tools and techniques. This gap was also identified by the lack of formal technology planning and management tools and processes being used in the two instrumentation supply chains studied. The technology planning and management lifecycle model developed in this thesis aims to address the key generic issues of appropriate tool selection and when to apply the selected tools. The purpose of the lifecycle model is to enable organisations to tailor the process so that it can be easily incorporated into their business processes. The aspiration is that the implementing organisation takes ownership of the process so that it can continuously plan and manage its technology rather than be reliant on a third party facilitating or owning the process.

A study was conducted into two instrumentation supply chains and was based upon research literature, best practice and a series of issues from the participating organisation’s experiences and outputs from the DTI Intersect Faraday Partnership meetings (the Intersect Faraday Partnership is managed by Sira and NPL). The main finding from the study is that formal technology planning and management tools are not being used within the instrumentation supply chains. This leads to ineffective technology planning and management within these supply chains which in turn has given rise to missold technology in one supply chain and a lack of innovation in the other. The reason for the lack of use of such tools is due to a lack of awareness of the tools and a lack of supporting business process framework in which to use them. The result of the study was that a list of technology

planning and management issues was identified and the following conclusions were reached regarding the three research questions posed:

Question 1: How is technology planning and management used in the R & D and Final User stages of the instrumentation supply chains?

Conclusion: Formal technology planning and management tools are not widely used for the development of instrumentation throughout the supply chain. Some more informal and ad hoc approaches are used.

Question 2: How effective are current technology planning and management tools and processes within the instrumentation supply chain?

Conclusion: The answer to this question appears to be “not very” or “not at all” since formal technology planning tools are not being fully utilised in the supply chain.

Question 3: What effect do instruments have on Customer/End User and Final User business performance with regard to their use in R & D facilities and providing added value to the Final User?

Conclusion: From the study the outcome was fairly inconclusive. This was a reflection of the ad hoc approach to instrument development and absence of any formal way of selecting and measuring instrumentation’s effectiveness as part of a business process.

The key observation from the study was that formal technology planning tools were not widely being used for the development of instrumentation throughout the supply chain. However, there were more informal approaches, for example, using experience and “gut-feel” and gathering information from customers, the scientific community and precision farming community. The reason for this in organisation 1’s supply chain is due to the instrumentation suppliers being very (almost too much) market driven. Suppliers waited until a broad base of customers identified new needs and technology before carrying out developments. Suppliers may make incremental improvements to existing product ranges that tend to be evolutionary rather than revolutionary. This leads to a very small amount of innovation coming from these suppliers. There was also a lack of awareness of what tools did exist and there was no structure that allowed technology planning to be incorporated as part

of an already busy business process. However, precision farming has been in the past very much pushed by technology. Suppliers tended to identify new technology and an application before carrying out developments but these applications did not always have a sound business case.

The tools that were used by the instrumentation customer community included discrete event simulation, brainstorming (committee of experts), roadmapping, technology monitoring (conferences journals etc.) and prototyping. The instrumentation supplier community that did use formal tools used brainstorming (committee of experts), focus groups, roadmapping, technology monitoring (conferences journals etc.), prototyping and experience and gut feel. Discrete event simulation is successfully used to explore process bottlenecks. Brainstorming provided mixed responses and depended on the quality and number of 'experts'. Roadmapping was found to get very complicated very quickly and required to be focused on a specific industry. It was usually used to focus on core rather than non-core technologies within the instrumentation customer community. Technology monitoring was found to be very time consuming and laborious in the collection of information. In addition small suppliers found it difficult to identify which technology to back. Prototypes are used to gain buy-in to new concepts due to it being hard to justify step changes in technology with just a paper study. The author's own experience from the defence and aerospace sectors also supports this view.

In addition to the technology follower strategy adopted by the suppliers, organisation 1 tended to drive technology advances in its instrumentation. Organisation 1's ability to develop instrumentation and to then pass on a detailed specification was, to a certain extent, stifling the innovation from its suppliers. Organisation 1, whilst it may use technology planning tools in its core activity of pharmaceutical development (untested by this study), it did not use these tools for the development of instrumentation.

The study also revealed 101 observations associated with technology planning and management. However, the most important observation was that the majority of organisations were not using a formal process for technology planning and those that were carried out were ad hoc. The most common reason for this was the lack of awareness of any formal tools and techniques and any that were used produced dubious results.

The technology planning and management lifecycle model developed in this thesis addresses the key observation from the study by ‘plugging’ the gaps in the existing range of tools and providing a framework that indicates when to use particular tools. The model also addresses the 101 issues identified by the study. The aim of this model is to put some science and management back into technology development rather than it just being a good thing to do. The technology planning and management lifecycle model supports the modelling approach used by Dr Michael Emes to model instrumentation use and procurement as part of the EPSRC Intersect Faraday Partnership Instrumentation Supply Chain Analysis and Modelling Project. The three-stage approach for modelling a company that uses instrumentation for Research and Development is summarized in Figure 1 on page 26 (Emes et al, 2005).

The first stage is to put the activities of the business into context by building a stakeholder model and to see how this influences the business model. This model shows how the business meets the needs of the customer. The modeller can now consider how the business goes about meeting its goals.

The second stage is to examine in detail the instruments that the business currently uses and the processes they participate in to deliver the end product. This is specific to the industry or business in question.

The third and final stage is to link the ‘top down’ business model that was described in Stage 1 and ensure that the stakeholders’ needs are satisfied, with the ‘bottom up’ use of instruments and processes by the organisation. This marriage is the function of the Technology Planning and Management Lifecycle Model, which incorporates the company’s research strategy (its choice of what areas to research), supply chain strategy (how prospective suppliers are identified and approved, and what the purchasing protocols are) and instrument procurement strategy (roles and responsibilities relating to procurement in the company). It should be noted that Figure 1 refers to the modelling of instrument use for R&D, however, it would be just as valid to replace ‘instruments’ with ‘products’, or ‘services’ etc and the R&D context could be replaced by other business functions or processes. Hence this approach is generic.

The technology planning and management lifecycle model was tested in part by a hypothetical example and by a series of field trials. However, the complete lifecycle of the model could not be tested within the scope of the EPSRC Intersect Faraday Partnership Instrumentation Supply Chain Analysis and Modelling Project. These untested parts of the lifecycle model will, therefore, need to be explored further through implementation of this model within organisations and any follow-on projects.

The results of the trials revealed a number of observations:

- The technology planning process requires buy-in from the participants.
- Technology workshops need to establish a whole system view.
- Technology workshops need to establish value.
- Timing is very important.
- Definition of terms needs to be established.
- A generic technology planning and management process needs to be tailored in order for it to be implemented within an organisation.
- Workshops need to contain an opportunistic element.
- Workshops require a Technology Domain Expert.
- Roadmaps need to be more than just technology maps and need to chart where one wants to be and how to get there. Technology maps should include:
 - Drivers
 - Business case (from different perspectives) of why you need to get to where you want to be
 - External Factors & Monitoring.
 - Enablers
 - Political, buy-in, expectation management (higher management)
 - Skills, training, support systems
 - Credibility, ownership, responsibilities
 - Technology
 - Capability survey
 - Technologies
 - Standards

- Implementation strategy
- Expectation management (user).

The last observation from the field trials is the most important. The aim of the technology planning and management lifecycle model was to be generic so that it can be adopted by all organisations. However, from the field trials it was concluded that the model requires tailoring to suit the context in which it is to be applied. The lifecycle model and the tools have therefore been translated into a tool kit that will enable easier adoption and help organisations with technology planning and management.

The main outcome from this thesis is an improved generic technology planning and management lifecycle model and a tool kit to help tailor it to an organisation's context.

9.2 Further Work

Although tested by the field trials in a number of examples, the model still needs refining, tailoring and optimising for different applications. Implementing the model in a number of industrial applications can be used to refine and optimise the model.

The model also needs testing in the area of 'implementation and monitoring of the technology plan' as it was not addressed by the field trials. Again this can be achieved through implementation.

The model needs a supporting training programme to facilitate companies to take ownership of the process and implement it. This training needs developing and the whole model needs to be disseminated.

During the review of existing technology planning tools, it was decided that the investigation of the use of Complexity Theory for technology planning was beyond the scope of this project. However, it would make an interesting topic for further work in this field.

In addition, it is proposed that a number of outcomes from the technology planning field trials are pursued. These include the adoption of the roadmaps for both the MSSL Solar Physics group and the Precision Farming Alliance. It has also been proposed that other

science groups within MSSL adopt the technology planning process to plan future technology requirements for future science missions.

9.3 Dissemination

The outputs from this thesis include the following contributions to courses, publications, reports, and presentations.

9.3.1 Courses

Some of the material from this thesis has been incorporated in the Technology Planning session of Cohort 4 and 5 of the BAE Systems MSc in Systems Engineering course and in an Introduction to Systems Engineering course for QinetiQ.

9.3.2 Publications

Cowper D, Emes M, & Smith A, (2004), **A Systems Engineering Process Model for ‘By Default’ Systems Integrators**, International Council On Systems Engineering (INCOSE) International Conference, 2004, Toulouse 20th – 24th June 2004

Cowper D, Emes M, & Smith A, (2005), **From Bespoke To Commercial Off The Shelf (COTS) - Classification Of Product Maturity**, Systems Engineering Journal, Wiley Periodicals Inc. Submitted awaiting publishing Vol TBD, pTBD, 2005.

9.3.3 Reports

Interim Report To Intersect on the Study’s Findings

Workshop report for GSK

Workshop report for PFA

Workshop report for MSSL Solar Physics Group

Technology Planning and Management Lifecycle UML Model report for project team

Review of Technology Planning Tools report for project team

Technology Planning and Management Tool Kit report for project team

9.3.4 Presentations

End of Phase 1 Report to GSK

End of Phase 2 Report to GSK

End of Phase 1&2 Report to Syngenta

Study Findings for Syngenta Senior Marketing Management

Building A World Class Biosensor Supply Chain – Lessons Learned From the Study to Intersect Faraday Partnership, 7th October 2004.

Using UML To Model Business Processes to IEE UML for Systems Engineering Seminar, 17th February 2005

REFERENCES

- Allen R E, (1990), **The Concise Oxford Dictionary**, Oxford, Clarendon Press, Edited by Allen R E, p130, p614, p615, p1253.
- Altshuller G, (1998), **40 Principles TRIZ Keys To Technical Innovation**, Translated, edited and new material by Shulyak L, Worcester, USA, Technical Innovation Centre Inc., pp11-21, pp23-103, pp123-128, p129.
- Asch (1964), cited by Twiss B, (1986), **Managing Technological Innovation**, Harlow, Longman Group Ltd., p223-224.
- Barley S R, (1983), **Semiotics and the Study of Occupational and Organizational Culture**, Administrative Science Quarterly, 28, p394.
- Betz F, (1998), **Managing Technological Innovation – Competitive Advantage from Change**, New York, John Wiley & Sons Inc, pp159-163, pp166-169, p170, pp174-175, p176, p177.
- Birnbaum M H, (1998), **Measurement, Judgment and Decision Making**, San Diego, Academic Press, pp1-3.
- Bossert J L, (1991), **Quality Function Deployment – A Practitioner's Approach**, Wisconsin, ASQC Quality Press, pp1-8.
- Braun E, (1998), **Technology in Context – Technology Assessment for Managers**, London, Routledge, p55.
- Camp, (1989), cited by Cardullo M W, (1996), **Introduction To Managing Technology**, Taunton, Research Studies Press Ltd, p259.
- Campbell D (1975), cited by Yin R K, (1994), **Case Study Research – Design and Methods**, Thousand Oaks, Sage Publications, pp25-26.
- Cardullo M W, (1996), **Introduction To Managing Technology**, Taunton, Research Studies Press Ltd, p103, p259, p260, p263.
- Checkland P, (1981), **Systems Thinking, Systems Practice**, Chichester, John Wiley.
- Christensen C M, (1997), **The Innovator's Dilemma – When New Technologies Cause Great Firms To Fail**, Boston, Harvard Business School Press.
- Cohen L, (1995), **Quality Function Deployment – How To Make QFD Work For You**, Reading MA, Addison-Wesley Publishing Company.
- Cooper & Kleinschmidt, (1995), cited by Cardullo M W, (1996), **Introduction To Managing Technology**, Taunton, Research Studies Press Ltd, p260.

- Cooper A & Schendel D, cited by Shanklin W L & Ryans J K, (1985), **Marketing High Technology**, Massachusetts, Lexington Books, pp88-89, 89-90.
- Cowper D D, (1997), **Matrix Management – Superstructure or Gridlock?**, MBA Dissertation, University of Surrey, p48.
- Cowper D, Emes M, & Smith A, (2004), **A Systems Engineering Process Model for ‘By Default’ Systems Integrators**, International Council On Systems Engineering (INCOSE) International Conference, 2004, Toulouse 20th – 24th June 2004
- Cowper D, Emes M, & Smith A, (2005), **From Bespoke To Commercial Off The Shelf (COTS) - Classification Of Product Maturity**, Systems Engineering Journal, Wiley Periodicals Inc. Submitted awaiting publishing Vol TBD, pTBD, 2005.
- Cowper D, & Smith A, (2002), **Sharpening Our Axes**, Engineering Management Journal, Institution of Electrical Engineers, Vol. 12 No. 6, December 2002, pp261-268.
- Crosby cited by Omachonu V K & Ross J E, (1995), **Principles of Total Quality**, London, Kogan Page Ltd, p10.
- Curnock A, (1996), **Quantitative Methods in Business**, Cheltenham, Stanley Thornes Publishers, pp 11-13.
- Denzin NK & Lincoln Y S, (1998), **The Landscape of Qualitative Research – Theories and Issues**, Thousand Oaks, Sage Publications, p11.
- DTI, Nov 1994, cited by Ho S K, (1995), **TQM An Integrated Approach**, London, Kogan Page, p117.
- Ellmer E, Emmerich W & Finkelstein A, (1998), **Process Technology Implications of Procurement Processes: Some Initial Observations**, in Software Process Technology, Proc. Of the 6th European Workshop, EWSPT ‘98, Lecture Notes in Computer Science 1487 (Springer Verlag), pp105-110.
- Emes M, Cowper D & Smith A, (2005), **Using UML to Model Business Processes – A Case Study Based On Instrumentation Use and Procurement**, IEE Seminar on UML for Systems Engineering, Savoy Place, London, 17th February 2005.
- Eriksson HE & Penker M, (2000), **Business Modeling with UML – Business Patterns At Work**, New York, John Wiley & Sons Inc., pp419-427.
- Farbey B & Finkelstein A, (2001), **Evaluation in Software Engineering: ROI, But More Than ROI**, in Proc. Of the 3rd International Workshop on Economics-Driven Software Engineering Research (EDSER-3 2001), 23rd International Conference on Software Engineering.
- Feldman M S, (1995), **Strategies for Interpreting Qualitative Data**, Thousand Oaks, Sage Publications, pp1-21.

- Floyd C, (1997), **Managing Technology for Corporate Success**, Aldershot, Gower, p1.
- Ford D & Saren M, (1996), **Technology Strategy for Business**, London, International Thompson Business Press, p1, p33, p46, p49, p55, p59, p183.
- Fowler J F, (1993), **Survey Research Methods**, London, Sage Publications, pp130-131.
- Frankel E G, (1990), **Management of Technological Change – The Great Challenge of Management to The Future**, Dordrecht, The Netherlands, Kluwer Academic Publishers, p86.
- Gjerdrum J, Shah N & Papageoriou L G, (2001), **‘Transfer Prices for Multi-Enterprise Supply Chain Optimisation’** Ind. Eng. Chem. Res. 40, The American Chemical Society, pp1650-1660.
- Gormley K, Fishenden J C & Scherer W T, (2004), **‘Optimisation of Research and Development Investment Strategies’**, INCOSE 2004 – 14th Annual International Symposium Proceedings, Toulouse, France, 21st -24th June 2004.
- Gotel OC Z & Finkelstein A C W, (1996), **An Analysis of the Requirements Traceability Problem**, in Software Change Impact Analysis, Arnold, R. & Bohnert, S. eds. (IEEE Computer Society Press).
- Hall P D, (1968), **Technological Forecasting for Computer Systems**, Proceedings from National Conference on Technological Forecasting, University of Bradford, 1968.
- Hazeltine B & Bull C, (1999), **Appropriate Technology – Tools Choices and Implications**, San Diego, Academic Press, p2.
- Hill C W L & Jones G R, (1995), **Strategic Management Theory – An Integrated Approach**, Boston, Houghton Mifflin Co., p80.
- Ho S K, (1995), **TQM An Integrated Approach**, London, Kogan Page, p
- Hoinville G, Jowell R, et Al, (1977), **Survey Research Practice**, Aldershot, Gower, p125.
- Holt J, (2001), **UML For Systems Engineering – Watching The Wheels**, London, IEE Publications.
- Institute for Manufacturing, (2002), **Foresight Vehicle Technology Roadmapping – Strategic Research Requirements For Future Road Transport**, Industry Consultation document, 9th January 2002, issues by Institute for Manufacturing, Cambridge, p1.
- Ireland D & Trevisan P, (2001), **‘Measurement and the Networked Future’**, IEE Review, November 2001, pp49-53.

- Jantsch E, (1967), **Technology Forecasting in Perspective**, Organisation for Economic Co-operation and Development, Paris, p145.
- Johnson G & Scholes K, (1993), **Exploring Corporate Strategy**, London, Prentice Hall, p80, p105.
- Jorgensen D L, (1989), **Participant Observation – A Methodology for Human Studies**, California, Sage Publications, pp12-34, 82-95.
- Kotler P, (1994), **Marketing Management – Analysis, Planning, Implementation and Control**, London, Prentice Hall International, p238.
- Lanner Group, (2002), **Witness Product Overview - Business Applications**, Promotional Material.
- Macaulay L A, (1996), **Requirements Engineering**, London, Springer-Verlag London Ltd p9,
- Mankins J C, (1995), **Technology Readiness Levels – A White Paper**, Advanced Concepts Office, Office of Space Access and Technology, NASA, 6th April 1995, p1, pp2-5.
- Mankins J C, (1998), **Research & Development Degree of Difficulty (R&D³ – A White Paper**, Advanced Concepts Office, Office of Space Access and Technology, NASA Headquarters, 10th March 1998, p1.
- Martino (1993), cited by Cardullo M W, (1996), **Introduction To Managing Technology**, Taunton, Research Studies Press Ltd, p61.
- McCurdy H E, (2001), **Faster, Better, Cheaper: Low-Cost Innovation In The US Space Program**, John Hopkins University Press.
- McKenna E, (1994), **Business Psychology & Organisational Behaviour – A Students' Handbook**, Hove, Lawrence Erlbaum Associates, Publishers, pp102-105, 463-496.
- Metz P D, (1996), **Integrating Technology Planning with Business Planning**, IEEE Engineering Management Review, Winter 1996, pp118-120.
- Mignogna R.P., (February 2001), **Introduction To Technology Trend Analysis, Part 2**, Technology Engineering Management Inc. (TEMI) e-Newsletter, www.temi.com/Newsletter/Feb01/TechTrends2.html .
- Miles M B & Huberman A M, (1994), **Qualitative Data Analysis**, Thousand Oaks, Sage Publications, p1.
- Miller S, (1984), **Experimental Design and Statistics**, Second Edition, London, Routledge, pp152-158.

- Morris C, (1996), **Quantitative Approaches In Business Studies**, 4th Edition, London, Pitman Publishing, p40.
- NASA Website, (2002), **Technology Readiness Levels**,
<http://isc.gsfc.nasa.gov/Technology/TRL/TRL.htm> .
- Omachonu V K & Ross J E, (1995), **Principles of Total Quality**, London, Kogan Page Ltd, p10, pp140-142, pp152-153, pp246-247.
- Oppenheim A N, (1992), **Questionnaire Design, Interviewing and Attitude Measurement**, New York, Pinter, pp128-130.
- Papageoriou L G, Rotstein G E & Shah N (2001), '**Strategic Supply Chain Optimisation for the Pharmaceutical Industries**', Ind. Eng. Chem. Res. 40, The American Chemical Society, pp275-286.
- Perrow C, (1999), **Normal Accidents: Living With High Risk Technology**, Princeton University Press.
- Petree J, (2002), **History of Chaos Theory**, www.wfu.edu/~petrejh4/HISTORYchaos.html (Author's Website), pp1-9
- Phaal R, Farrukh C & Probert D, (Nov 2001), **Technology Roadmapping: Linking Technology Resources to Business Objectives**, Centre for Technology Management, University of Cambridge, p1, pp5-8.
- Phaal R, Farrukh C & Probert D, (2001), **T-Plan The Fast Start to Technology Roadmapping – Planning Your Route To Success**, Institute for Manufacturing, University of Cambridge, piii.
- Pólya G, (1945), **How To Solve It – A New Aspect Of Mathematical Method**, Princetown, Penguin Books, pxxxvi)
- Porter M E, (1979), **How Competitive Forces Shape Strategy**, Harvard Business Review, March-April 1979.
- Rantanen K, Domb E, (2002), **Simplified TRIZ – New Problem Solving Applications For Engineers And Manufacturing Professionals**, London, St Lucie Press.
- Reinertsen D G, (1997), **Managing The Design Factory – A Product Developer's Toolkit**, New York, The Free Press, pp128-130.
- Rumbaugh, J., Jacobson, I. & Booch, G., **The Unified Modeling Language Reference Manual**, Addison Wesley Longman, 1999, p. 210
- Schulz A P, Clausing DP, Fricke E & Negele H, (2000), **Development and Integration of Winning Technologies as Key to Competitive Advantage**, Systems Engineering Journal, Vol.3, No. 4, 2000, John Wiley & Sons, Inc. pp185-186, p199.

- Semiconductor Industry Association, (1999), **International Technology Roadmap for Semiconductors – Overall Roadmap Technology Characteristics & Glossary**, 1999 Edition, http://public.itrs.net/files/1999_SIA_Roadmap/Home.htm .
- Shanklin W L & Ryans J K, (1985), **Marketing High Technology**, Massachusetts, Lexington Books, pp88-89, 89-90.
- Shulyak L, (1998), **40 Principles TRIZ Keys To Technical Innovation**, by Altshuller G, Translated, edited and new material by Shulyak L, Worcester, USA, Technical Innovation Centre Inc., p15, p16, p17, pp107-108.
- Sira & National Physical Laboratory (NPL), (1999), **Changing Practice in the UK Domestic Supply Chain for Instrumentation**, HMSO, pp8-34.
- Smith A, (2001), **Technology Planning**, Presentation at NMC & BEMC conference held at Harrogate, October 2001, University College London.
- Smith A, (2002), **Technology Management**, MSc in Systems Engineering Teaching Block B course notes, May 2002, University College London, p2.
- Smith A, (2003), **Systems Engineering**, Faraday Annual Workshop, 15th to 19th December 2003, University College London.
- Smith A, Cowper D D, & Emes M R, (2004), **Interim Report To the Intersect Faraday Partnership**, University College London.
- Steiner Marketing Website, (2002), **Product Needs Research For Product Line Planning**, <http://www.steinermarketing.com/index.htm>.
- Stevens R, Brook P, Jackson K, & Arnold S, (1998), **Systems Engineering – Coping with Complexity**, London, Prentice Hall, pp2-4, pp302-304.
- Stewart D W & Shamdasani P N, (1990), **Focus Groups – Theory and Practice**, London, Sage Publications, pp9-50, 57.
- Torrington D & Hall L, (1995), **Personnel Management – HRM In Action**, London, Prentice Hall, pp476-481.
- TRIZ website, (2000), **TRIZ FAQ**, www.triz.org/triz.htm, website managed by Rodman S of Technical Innovation Centre Inc.
- Twiss B, (1986), **Managing Technological Innovation**, Harlow, Longman Group Ltd., p75, p76, p217, p222, pp223-224, pp226-228.
- Von Neumann J, (1944), cited by Singh S, (1997), **Fermat's Last Theorem**, London, Fourth Estate, pp166-167.
- Vorley G, (1996), **Quality Management (Principles and Techniques)**, Guildford, Quality Management & Training (Publications), p107, p128.

- Webb A, (2002), **TRIZ: An Inventive Approach To Innovation**, Engineering Management Journal, Institution of Electrical Engineers, London, Vol. 12 No.3, June 2002, p122, p124.
- Wiley Student Wave website, (2005), **Technological Forecasting**, <http://www.wiley.com/college/dec/meredith298298/resources/addtopics/addtopics02a.html>.
- Wolf S & Smith R F M, (1990), **Student Reference Manual For Electronic Instrumentation Laboratories**, New Jersey, Prentice Hall, pp32-33, p483.
- Yin R K, (1994), **Case Study Research – Design and Methods**, Thousand Oaks, Sage Publications, pp4-9, p20, pp25-26.
- Zwicky F, cited by Betz F, (1998), **Managing Technological Innovation – Competitive Advantage from Change**, New York, John Wiley & Sons Inc, p176

APPENDIX 1

SUMMARY OF EXISTING TECHNOLOGY PLANNING TOOLS REVIEW

Tool/Process	Advantages	Disadvantages
Attribute Analysis	<ul style="list-style-type: none"> • Can identify a number of uses for a technological phenomenon in situations where this is not always obvious. • Technologies deployed in other industries can be introduced to solve problems/obtain competitive advantage in a company's own industrial segment. 	<ul style="list-style-type: none"> • Applications may be identified which are outside the scope of the organisation's business strategy.
Committees of Experts	<ul style="list-style-type: none"> • Use of committees of experts can provide an important view of technological change and direction of progress 	<ul style="list-style-type: none"> • Geographical dispersal of experts • Availability of the experts to attend a committee meeting • Committee may not reach an unbiased conclusion • Persuasive or articulate committee members may bias the discussion and decisions. • Position of authority and scientific reputation can bias the committee • The natural reluctance to change publicly a view previously strongly expressed • The "band-wagon" affect where individuals will not disagree with the majority view in spite of their own judgement
Complexity Theory	<ul style="list-style-type: none"> • May offer a way of viewing the technology development process in a new light. 	<ul style="list-style-type: none"> • Not been utilised in technology planning and is therefore untried in this field.
Delphi	<ul style="list-style-type: none"> • Overcomes the disadvantages of committees whilst retaining the advantage a panel of experts can give on technology trends etc. 	<ul style="list-style-type: none"> • Quality of the technology forecast relies on the "experts" selected for the panel. • Panel member selection can be biased, thus not obtaining a good cross section of expert views. • Anonymity can relieve members of accountability leading to careless responses. • Consensus gives a conservative view of the future and hence reinforces existing paradigms. • Offers little insight into the members' responses. • Responses can be at best a series of guesses and the averaging of these can give a spurious sense of scientific accuracy.

Tool/Process	Advantages	Disadvantages
Discrete Event Simulation	<ul style="list-style-type: none"> • Good for simulation various scenarios and testing the sensitivity of each for evaluation purposes. • Good at establishing bottlenecks within processes. 	<ul style="list-style-type: none"> • Is only as good as the data supplied to the simulation.
Game Theory	<ul style="list-style-type: none"> • Useful exploring options for technology in either pure or mixed strategies. • Can be applied with nature or an actual competitor as an opponent to play through the outcome of the game. • The role of chance events and matrix representation of payoffs are useful inputs to decision making. 	<ul style="list-style-type: none"> • Establishing the rules/game parameters can be difficult.
Metz 5 “best practices”	<ul style="list-style-type: none"> • Based on case studies and is a collation of what works in practice. • Provides a framework of business culture required to support good technology planning. 	<ul style="list-style-type: none"> • Very high level – no detail of underlying tools required to support the process. • Requires organisational cultural change that may be difficult and takes a long time to implement.
Needs Research	<ul style="list-style-type: none"> • Provides market pull for the development of technology and ensures that the customer values the technology being invested in. 	<ul style="list-style-type: none"> • Cannot be carried out in isolation. Other techniques are required to deliver the forecasting and planning of these technologies that are identified.
Nominal Group	<ul style="list-style-type: none"> • Overcomes the problems of: <ol style="list-style-type: none"> 1. Committee may not reach an unbiased conclusion 2. Persuasive or articulate committee members may bias the discussion and decisions 3. Position of authority and scientific reputation can bias the committee 4. The natural reluctance to change publicly a view previously strongly expressed 5. The “band-wagon” affect where individuals will not disagree with the majority view in spite their own judgment. 	<ul style="list-style-type: none"> • Geographical dispersal of experts • Availability of the experts to attend a committee meeting • Ability of the group leader to maintain a structured approach to the meeting
Relevance Trees	<ul style="list-style-type: none"> • Allows the feasibility of a technology to be established – if no feasible path can be found then the technological mission cannot be achieved. • Determines the optimum R&D programme by analysing the paths through the hierarchy. • Selection and planning of specific technology projects. • Establishing performance objectives for the R&D programme. 	<ul style="list-style-type: none"> • Can end up being very large in order to explore all the possible iterations of all the desired features of a technical system.

Tool/Process	Advantages	Disadvantages
	<ul style="list-style-type: none"> Identifying risk areas on contributing technologies where performance and time are critical – detailed technology forecasts will be required for these technologies. Useful in quantitative analysis and is also an aid for decision-making. 	
Scenarios	<ul style="list-style-type: none"> Can be used when time series data, panels of experts and models are unavailable. Can be used to integrate results from a number of tools. Can provide a wide range of possible outcomes. 	<ul style="list-style-type: none"> Can produce more unrealistic results than useful ones. Scenarios can become very complex very quickly and can be an effort intensive process.
Schema & Morphological Analysis	<ul style="list-style-type: none"> Can be used to generate a matrix of desired features and alternative solutions. Good tool for focusing the mind on what technology can produce the desired features. Most technology planning is based upon the concept of Morphological Analysis of looking at all of a technical system's structural features. Those that do use the technique unanimously endorse its merits for stimulating new ideas. 	<ul style="list-style-type: none"> Mainly used for reviewing designs rather than technology forecasting. Can be very clumsy and can end up being very large in order to explore all the possible iterations of all the desired features of a technical system. Little take up by high technology companies.
Technological Trends – S Curve	<ul style="list-style-type: none"> Good for forecasting the rates of change of technology. Good for identifying natural limits of technology. 	<ul style="list-style-type: none"> Relies on detailed knowledge of science base of the technology being forecast. Forecasts rate of technological change, but not the direction. Does not determine how an organisation should influence the change in technology. Does not provide a strategy of how to influence the technology.
Technology Audits	<ul style="list-style-type: none"> Identifies an organisation's ability to successfully develop and introduce new technology. Can reveal what technology forecasting is required by the organisation. 	<ul style="list-style-type: none"> Cannot be used in isolation. Needs to be part of an integrated process, which includes forecasting techniques. Definition of technology standards against which to audit.
Technology Benchmarking	<ul style="list-style-type: none"> Allows organisations to compare differences between themselves, their competitors and "world class" "best practice" Cultural Change – being able to set realistic and rigorous new targets. 	<ul style="list-style-type: none"> Difficult to identify organisations that are world class in a specific technical area. Difficult to define what "world class" is. Time to carry out the benchmarking process. Co-operation of other organisations to obtain comparison data.

Tool/Process	Advantages	Disadvantages
	<ul style="list-style-type: none"> • Performance Improvement – identifying and defining specific gaps in the company's performance. • Human Resources – provides a basis for identifying gaps between an individual's skills and world class and can provide a basis for training. 	<ul style="list-style-type: none"> • Organisation's experience in the benchmarking process. • Identification of the link between best practices and improved performance, due to unknown underlying factors.
Technology Focus Groups and Technology Footprinting	<ul style="list-style-type: none"> • Allows organisations to identify the technologies required by their industry. • Allows organisations to identify the competitive impact of these technologies. • Allows organisations to identify the organisation's competitive impact in each technology. • Allows organisations to plan for what the organisation should do to invest in each technology. 	<ul style="list-style-type: none"> • Can be time consuming. • Requires a good knowledge of how competitive technology is. • It also does not give any information about how to reposition a technology and when to reposition.
Technology Monitoring / Awareness	<ul style="list-style-type: none"> • Provides a systematic gathering and processing of technology information. • Can provide a random association of facts that would not normally occur in a formal framework. 	<ul style="list-style-type: none"> • Cannot be used in isolation and requires integration with the people with the ideas and other forecasting tools.
Technology Readiness Levels	<ul style="list-style-type: none"> • Provides a systematic metric/measurement system. • Allows not only the technology's maturity to be quantified, but also allows comparison of maturity between different technology types. 	<ul style="list-style-type: none"> • TRLs are focused on maturity in terms of investment against NASA's systems lifecycle. • Complementary measures need to be added to broaden the picture of maturity.
Technology Roadmaps	<ul style="list-style-type: none"> • Similar advantages to focus groups and technology footprinting: • Allows organisations to identify the technologies required by their industry. • Allows organisations to identify the competitive impact of these technologies. • Allows organisations to identify the organisation's competitive impact in each technology. • Allows organisations to plan for what the organisation should do to invest in each technology. • Roadmapping provides a simple diagrammatic view of future plans. • Roadmapping provides a summary of what is going to happen when. 	<ul style="list-style-type: none"> • Difficulty in initiating the roadmapping process. • Difficulty in sustaining the process once initiated. <p>(These difficulties are addressed in the process researched by the Cambridge Institute for Manufacturing)</p> <ul style="list-style-type: none"> • Most maps do not show the next level of detail, are difficult to keep up to date and has no measure of realism in its timescales. • There is no scale or weighting used to allow for a comparison between technologies. • There is no costing element to the map. • Roadmapping is also a difficult concept that can get very complex very fast.

Tool/Process	Advantages	Disadvantages
	<ul style="list-style-type: none"> • The roadmap also helps to avoid writing off ideas just because they are not technically feasible today. 	
TRIZ	<ul style="list-style-type: none"> • Based on research into a large number (400,000) of technical patents. • Useful tool in assisting with the thought process of breaking down problems into their component parts and taking a holistic, system-of-systems view of the problem. • Good approach to resolving technical conflicts. 	<ul style="list-style-type: none"> • The author has some reservations about the characteristics identified within the matrix and that this list is probably not exhaustive. • TRIZ contradiction matrix does not address powerful innovation stimulants such as economics and energy substitution. • Applying the contradiction matrix to software appears to be difficult. • There are instances when substantial abstractions are required before the principles can be applied. • The value of the TRIZ principles will diminish with time.

APPENDIX 2
SUMMARY OF THE 40 PRINCIPLES OF TRIZ
(ALTSHULLER, 1998, PP123-128)

1. Segmentation
 - a. Divide an object into interdependent parts.
 - b. Make an object sectional (for easy assembly or disassembly).
 - c. Increase the degree of an object's segmentation.
2. Extraction (Extracting, Retrieving, Removing)
 - a. Extract the "disturbing" part or property from an object.
 - b. Extract only the necessary part or property from an object.
3. Local Quality
 - a. Transition from homogeneous to heterogeneous structure of an object or outside environment (action).
 - b. Different parts of an object should carry out different functions.
 - c. Each part of an object should be placed under conditions that are most favourable for its operation.
4. Asymmetry
 - a. Replace symmetrical form(s) with asymmetrical form(s).
 - b. If an object is already asymmetrical, increase its degree of asymmetry.
5. Consolidation
 - a. Consolidate in space homogeneous objects, or objects destined for contiguous operations.
 - b. Consolidate in time homogeneous or contiguous operations.
6. Universality
 - a. An object can perform several different functions; therefore, other elements can be removed.
7. Nesting
 - a. One object is placed inside another. That object is placed inside a third one. And so on...
 - b. An object passes through a cavity in another object.
8. Counterweight
 - a. Compensate for the weight of an object by combining it with another object that provides a lifting force.
 - b. Compensate for the weight of an object with aerodynamic or hydrodynamic forces influenced by the outside environment.
9. Prior Counteraction
 - a. Preload counter tension to an object to compensate excessive and undesirable stress.

10. Prior Action
 - a. Perform required changes to an object completely or partially in advance.
 - b. Place objects in advance so that they can go into action immediately from the most convenient location.
11. Cushion in Advance
 - a. Compensate for the relatively low reliability of an object with emergency measures prepared in advance.
12. Equipotentiality
 - a. Change the condition of the work in such a way that it will not require lifting or lowering an object.
13. Do It in Reverse
 - a. Instead of the direct action dictated by a problem, implement an opposite action (i.e. cooling instead of heating).
 - b. Make the movable part of an object, or outside environment, stationary – and stationary part moveable.
 - c. Turn an object upside-down.
14. Spheroidality
 - a. Replace linear parts with curved parts, flat surfaces with spherical surfaces, and cube shapes with ball shapes.
 - b. Use rollers, balls, and spirals.
 - c. Replace linear motion with rotational motion; utilise centrifugal force.
15. Dynamicity
 - a. Characteristics of an object, or outside environment, must be altered to provide optimal performance at each stage of an operation.
 - b. If an object is immobile, make it mobile. Make it interchangeable.
 - c. Divide an object into elements capable of changing their position relative to each other.
16. Partial or Excessive Action
 - a. If it is difficult to obtain 100% of a desired effect, achieve more or less of the desired effect.
17. Transition Into a New Dimension
 - a. Transition one-dimensional movement, or placement, of objects into two-dimensional; two-dimensional to three dimensional, etc.
 - b. Utilise multi-level composition of objects.
 - c. Incline an object, or place it on its side.
 - d. Utilise the opposite side of a given surface.
 - e. Project optical lines onto neighbouring areas, or onto the reverse side, of an object.
18. Mechanical Vibration
 - a. Utilise oscillation.
 - b. If oscillation exists, increase its frequency to ultrasonic.
 - c. Use the frequency of resonance.
 - d. Replace mechanical vibrations with piezo-vibrations.
 - e. Use ultrasonic vibrations in conjunction with an electromagnetic field.

19. Periodic Action
 - a. Replace a continuous action with a periodic one (impulse).
 - b. If the action is already periodic, change its frequency.
 - c. Use pulses between impulses to provide additional action.
20. Continuity of Useful Action
 - a. Carry out an action without a break. All parts of the object should constantly operate at full capacity.
 - b. Remove idle and intermediate motion.
 - c. Replace “back-and-forth” motion with a rotating one.
21. Rushing Through
 - a. Perform harmful and hazardous operations at very high speed.
22. Convert Harm Into Benefit
 - a. Utilise harmful factors – especially environmental – to obtain a positive effect.
 - b. Remove one harmful factor by combining it with another harmful factor.
 - c. Increase the degree of harmful action to such an extent that it ceases to be harmful.
23. Feedback
 - a. Introduce feedback.
 - b. If feedback already exists, change it.
24. Mediator
 - a. Use an intermediary object to transfer or carry out an action.
 - b. Temporarily connect the original object to one that is easily removed.
25. Self-service
 - a. An object must service itself and carry out supplementary and repair operations.
 - b. Make use of waste material and energy.
26. Copying
 - a. A simplified and inexpensive copy should be used in place of a fragile original or an object that is inconvenient to operate.
 - b. If a visible optical copy is used, replace it with an infrared or ultraviolet copies.
 - c. Replace an object (or system of objects) with their optical image. The image can then be reduced or enlarged.
27. Dispose
 - a. Replace an expensive object with a cheap one, compromising other properties (i.e. longevity).
28. Replacement of Mechanical System
 - a. Replace a mechanical system with an optical, acoustical, thermal or olfactory system.
 - b. Use an electric, magnetic or electromagnetic field to interact with an object.
 - c. Replace fields that are:
 1. Stationary with mobile.
 2. Fixed with changing in time.
 3. Random with structured.
 - d. Use fields in conjunction with ferromagnetic particles.
29. Pneumatic or Hydraulic Constructions
 - a. Replace solid parts of an object with a gas or liquid. These parts can now use air or water for inflation, or use pneumatic or hydrostatic cushions.

30. Flexible Membranes or Thin Films
 - a. Replace customary constructions with flexible membranes or thin film.
 - b. Isolate an object from its outside environment with flexible membranes or thin films.
31. Porous Material
 - a. Make an object porous, or use supplementary porous elements (inserts, covers, etc.).
 - b. If an object is already porous, fill pores in advance with some substance.
32. Changing the Colour
 - a. Change the colour of an object or its environment.
 - b. Change the degree of translucency of an object or its environment.
 - c. Use colour additives to observe an object, or process which is difficult to see.
 - d. If such additives are already used, employ luminescent traces or trace atoms.
33. Homogeneity
 - a. Objects interacting with the main object should be made out of the same material (or material with similar properties) as the main object.
34. Rejecting and Regenerating Parts
 - a. After completing its function, or becoming useless, an element of an object is rejected (discarded, dissolved, evaporated, etc.) or modified during its work process.
 - b. Used-up parts of an object should be restored during its work.
35. Transformation of Properties
 - a. Change the physical state of the system.
 - b. Change the concentration or density.
 - c. Change the degree of flexibility.
 - d. Change the temperature or volume.
36. Phase Transition
 - a. Using the phenomena of phase change (i.e. a change in volume, the liberation or absorption of heat, etc.).
37. Thermal Expansion
 - a. Use expansion or contraction of material by changing its temperature.
 - b. Use various materials with different coefficients of thermal expansion.
38. Accelerated Oxidation
 - a. Make transition from one level of oxidation to the next higher level:
 1. Ambient air to oxygenated.
 2. Oxygenated to oxygen.
 3. Oxygen to ionised oxygen.
 4. Ionised oxygen to ozoned oxygen.
 5. Ozoned oxygen to ozone.
 6. Ozone to singlet oxygen.
39. Inert Environment
 - a. Replace a normal environment with an inert one.
 - b. Introduce a neutral substance or additives into an object.
 - c. Carry out the process in a vacuum.
40. Composite Materials
 - a. Replace homogeneous materials with composite ones.

APPENDIX 3

CHARACTERISTICS OF TECHNICAL SYSTEMS (ALTSHULLER, 1998, P129) AND PART OF THE TRIZ CONTRADICTION MATRIX (RANTANEN & DOMB, 2002, PP194-209)

1. Weight of a mobile object.	2. Weight of a stationary object.
3. Length of a mobile object.	4. Length of a stationary object.
5. Area of a mobile object.	6. Area of a stationary object.
7. Volume of a mobile object.	8. Volume of a stationary object.
9. Speed.	10. Force.
11. Tension/Pressure.	12. Shape.
13. Stability of composition.	14. Strength.
15. Time of action of a moving object.	16. Time of action of a stationary object.
17. Temperature.	18. Brightness.
19. Energy spent by a moving object.	20. Energy spent by a stationary object.
21. Power.	22. Loss of energy.
23. Loss of substance.	24. Loss of information.
25. Loss of time.	26. Amount of substance.
27. Reliability.	28. Accuracy of measurement.
29. Accuracy of manufacturing.	30. Harmful factors acting on an object from outside.
31. Harmful factor developed by an object.	32. Manufacturability.
33. Convenience of use.	34. Repairability.
35. Adaptability.	36. Complexity of a device.
37. Complexity of control.	38. Level of automation.
39. Capacity/Productivity.	

Characteristics Of Technical Systems (Altshuller, 1998, p129)

The following table details part of Altshuller's (cited by Rantanen & Domb, 2002, pp194-209) Contradiction Matrix. The full matrix is 39 by 39 covering each of the 39 characteristics of technical system plotted against each of the 39 characteristics. Numbers (in bold) for improved/ worsened feature refer to the Characteristics Of Technical System above. The numbers in the matrix refer to the principles to resolve the conflict listed in appendix 2. The grey highlighted areas refer to the examples given in chapter 2.

		Worsened Feature									
		1	2	3	4	5	6	7	8	9	10
Improved Feature	1	all	all	15, 8, 29,34	all	29,17, 38, 34	all	29, 2, 40,28	all	2,8, 15,38	8, 10, 18,37
	2	all	all	all	10, 1, 29,35	all	35,30, 13, 2	all	5, 35, 14, 2	All	8, 10, 19,35
	3	8,15, 29,34	all	all	all	15,17, 4	all	7, 17, 4, 35	all	13, 4, 8	17, 10, 4
	4	all	35,28, 40,29	all	all	all	17, 7, 10,40	all	35, 8, 2, 14	All	28, 10
	5	2, 17, 29, 4	all	14,15, 18, 4	all	all	all	7, 14, 17, 4	all	29,30, 4, 34	19,30, 35, 2
	6	all	30, 2, 14,18	all	26, 7, 9, 39	all	all	all	all	All	1, 18, 35,36
	7	2, 26, 29,40	all	1, 7, 4, 35	all	1, 7, 4, 17	all	all	all	29, 4, 38, 34	15, 35, 36,37
	8	all	35,10, 19,14	19,14	35, 8, 2, 14	all	all	all	all	All	2, 18, 37
	9	2, 28, 13,38	all	13,14, 8	all	29,30, 34	all	7, 29, 34	all	All	13,28, 15,19
	10	8, 1, 37,18	18,13, 1,28	17,19, 9, 36	28,10	19,10, 15	1, 18, 36,37	15, 9, 12,37	2, 36, 18, 37	13,28, 15,12	all
		Worsened Feature									
		11	12	13	14	15	16	17	18	19	20
Improved Feature	1	10,36, 37,40	14,10, 35,40	1, 35, 19,39	28,27, 18,40	5, 34, 31,35	all	6, 29, 4, 38	19, 1, 32	35,12, 34,31	all
	2	13,29, 10,18	13,10, 29,14	26,39, 1, 40	28, 2, 10,27	all	2, 27, 19, 6	28,19, 32,22	19,32, 35	all	18,19, 28, 1
	3	1, 8, 35	1, 8, 10,29	1, 8, 15,34,	8, 35, 29,34	19	all	10,15, 19	32	8, 35, 24	all
	4	1, 14, 35	13,14, 15, 7	39,37, 35	15,14, 28,26	all	1, 10, 35	3, 35, 38,18	3, 25	all	all
	5	10,15, 36,28	5, 34, 29, 4	11, 2, 13,39	3, 15, 40,14	6, 3	all	2,15, 16	15,32, 19,13	19,32	all
	6	10,15, 36,37	all	2, 38	40	all	2, 10, 19,30	35,39, 38	all	all	all
	7	6, 35, 36,37	1, 15, 29, 4	28,10, 1, 39	9, 14, 15, 7	6, 35, 4	all	34,39, 10,18	2,13, 10	35	all
	8	24,35	7, 2, 35	34,28, 35,40	9,14, 17,15	all	35,34, 38	35, 6, 4	all	all	all

APPENDIX 4
PROJECT REVIEW MEETING - TECHNOLOGY PLANNING ISSUES
RAISED AND ORGANISATION RESEARCH FOCUS AREAS

Project Review Meeting held on 11th December 2001

Amongst the issues to address in phase 1 are:

- Vendor competition and market control
- Technology push
- Technology misuse
- User buy-in
- Cost of ownership
- Lifecycle mismatch
- Interface compatibility and profusion of standards
- Compatibility with bespoke systems
- Influence
- Impact on bottom line
- Where does technology bite?

Discussion

A discussion session was held relating to the phase 1 issues mentioned above although in fact only the first issue was very fully addressed

The following points were made:

a) Vendor Competition

1. A big problem but slowly changing.
2. There is a large variability between suppliers.
3. There is a strong reluctance to change supplier when there has been a major investment in their hardware.
4. Supplier support is absolutely essential for the process industry.
5. Large companies (like HP) can appear arrogant and inflexible while small suppliers are more responsive.
6. Large suppliers monitor innovation from smaller companies, select the most saleable and incorporate in their product portfolio.
7. Large suppliers salespersons may not be interested in allowing any influence in new product development.
8. Should small and large suppliers be seen as elements of a system, both with their role. In this model many small companies have a lifecycle of innovation, production and evaporation/incorporation.
9. Small supplier development costs are high and so bespoke developments are expensive.

10. Small suppliers have limited capacity and few small suppliers produce a series of innovative products.
11. Small suppliers company lifecycle very constrained by the advantages of volume production which can suppress further innovation.
12. Few examples exist of people movement from large to small suppliers.
13. How are large suppliers structured internally?, how do they plan their technology?
14. Large suppliers – Evolution; Small suppliers – Revolution.
15. Some large suppliers are internally very fragmented (e.g. ABB) and act more like a federation of small suppliers?
16. Is it useful to consider three types of supplier:
 Large, institutional suppliers, good support, low responsivity.
 Large, fragmented suppliers, poor support, high responsivity.
 Small, dynamic suppliers, poor support, responsivity high->low.
17. Small suppliers have difficulty knowing what technology to back.
18. “There are standards for almost everything”.

b) Technology Push

- 1) Driven by standards.
- 2) Lack of sophistication in user can be an issue.
- 3) Is the user specifying correctly or not specifying at all – just picking from a catalogue.
- 4) The more functions the more opportunities for failure.
- 5) Misuse = lost opportunity.
- 6) User unaware of functionality – how much effort should be spent in making the user aware of available functionality?
- 7) Cost of ownership - Generally well addressed in terms of maintenance of process instrumentation. Not so well addressed in analytical instrumentation. Should include calibration, training, supplier lock, liability and expectations.

Project Review Meeting held on 8th March 2002

Selection of research areas:

- Organisation 1

a) High Throughput Chemistry

The natural choice. A new facility will soon becoming on line in a new building. It is therefore very timely and there would be plenty of opportunities for inputs.

b) Lab on a Chip

Very new with little historic data. Confidentiality will be an issue. Implementation of new technologies is very important.

It was unanimously agreed that the area of research selected shall be a) High Throughput Chemistry. However some consideration of Lab on a Chip will be included since this is anyway a legitimate extrapolation.

- Organisation 2

See minutes of the meeting held on 11 Dec 2001 for details of each area.

1. An existing manufacturing process – Easy to model, hard to validate large proposed changes but incremental small changes should be possible. – covered by organisation 1.
2. Proposed manufacturing process – due for operation in 2008. For the situation suggested nothing was yet on the ground although procurement of major items was expected soon. The situation could be quite fluid and would likely be pragmatic. – manufacturing process improvement has been well covered elsewhere. Also the new manufacturing process will be sited in the USA.
3. Final product usage – a new area for Organisation 2. The application of agrochemical was non-optimum and improved instrumentation could help- but how? – End User Instrumentation: Organisation 2 as part of the food chain. Want sales team to provide complete packages organisation 2 acting both as materials supply and systems integrator.

APPENDIX 5 INTERVIEW QUESTION CHECK LIST

Lead Interviewer's List of Headings and Prompt Questions

The questions listed below are for guidance only and are there to provide a prompt for the lead interviewer.

Ref	Research Question/ Proposition	Technology Issue	Interviewee					
			End User		Customer		Supplier	
			High Level	Low Level	High Level	Low Level	High Level	Low Level
		General Fact Finding						
1	B	Where do you see the company in ten years time?	•		•		•	
	Q3, P3.3	Vendor Competition & Market Control						
2	Q3, P3.3	Do you think that small suppliers of instruments are more responsive than large suppliers?	•	•	•	•		
3	Q1, P1.1	What issues affect the way in which you perform your role – i.e. what stops them doing their job effectively?	•	•	•	•	•	•
4	Q3, P3.3	Which instrumentation suppliers do you use and how would you categorise each one? Large, institutional suppliers, good support, low responsivity Large, fragmented suppliers, poor support, high responsivity Small, dynamic suppliers, poor support, responsivity high->low	•	•	•	•		
	Q1, P1.1	Technology Push						
5	Q1, P1.1	What are the issues associated with the capturing of end user requirements?			•	•	•	•
6	Q1, P1.1	Do you think briefings on latest technologies would be helpful?	•	•	•	•	•	•
	Q1, P1.2	Technology Misuse						
7	Q1, P1.2	What equipment do you require to perform your function within the organisation?		•		•		
8	Q1, P1.2	Have you ever known any unneeded or unused functions to cause an instrument to fail? What were the consequences?		•		•		
9	Q1, P1.2	Do you receive training on new instrumentation systems?		•		•		
	Q1, P1.1	User Buy-in						
10	Q1, P1.1	What information do you give the end user regarding the instrumentation needed to use your product?			•	•		
11	Q1, P1.1	What information do you give the end user regarding any training needed to use the instrumentation?			•	•		
12	Q1, P1.1	Is the end user involved with your technology planning process?			•	•	•	•
13	Q1, P1.1	Do you feel you are involved in the instrumentation suppliers' technology planning processes?	•	•				
	Q3, P3.2	Cost of Ownership						
14	Q3, P3.2	How important do you think this after sales care is for your customers?					•	•
15	Q3, P3.2	How do you rate the level of support you receive from your suppliers?	•	•	•	•		
16	Q3, P3.2	How important to you is the ability to switch between suppliers? How easy do you find it?	•	•	•	•		
17	Q3, P3.2	Do you take into account the cost of: Calibration? Training? Reliability? (Down time of plant, cost of time to sort out problem, etc.)	•	•	•	•		

Ref	Research Question/ Proposition	Technology Issue	Interviewee					
			End User		Customer		Supplier	
			High Level	Low Level	High Level	Low Level	High Level	Low Level
	Q2, P2.1	Lifecycle Mismatch						
18	Q2, P2.1	Are new instruments generally available when you need them?	•	•	•	•		
19	Q2, P2.1	How do you plan for the delivery of the 'right' instrument when your process requires it?	•	•	•	•		
20	Q2, P2.1	How does the ease with which you can update instrumentation affect process improvement?	•	•	•	•		
21	Q2, P2.1	How easy do you find this ability to upgrade your instrumentation?	•	•	•	•		
	Q1, P1.3	Interface Compatibility and Profusion of Standards						
22	Q1, P1.3	What instrumentation standards are you aware of?	•	•	•	•	•	•
23	Q1, P1.3	Do you find these standards useful in your use of instruments?		•		•		•
		Compatibility with Bespoke Systems						
	Q1, P1.1	Influence						
24	Q1, P1.1	How do you affect decisions that are made – in particular with regard to the procurement of equipment?	•	•	•	•		
25	Q1, P1.1	How do you make your decision?		•		•		
26	Q1, P1.1	What trade offs do you need to make?		•		•		
27	Q1, P1.1	How often do you find the right piece of equipment for the right price?		•		•		
	Q3, P3.1	Impact on Bottom Line						
28	Q3, P3.1	What are the major variables that affect the business' performance?	•		•		•	
	Q3, P3.1	Where Does Technology Bite?						
29	Q3, P3.1	How import is the use of instrumentation in the way in which the product is used?	•	•	•	•		
30	Q3, P3.1	What would happen if this instrumentation produced errors, failed or was unavailable?	•	•	•	•		
31	Q1, P1.1	What process does the organisation go through to plan for technology?	•	•	•	•	•	•

Second Interviewer's Question List with Priorities

The questions for each heading are ranked in order. The second interviewer follows the interview by the lead interviewer and then selects the top three questions, which have not already been addressed during the interview.

Ref	Research Question/ Proposition	Technology Issue	Interviewee					
			End User		Customer		Supplier	
			High Level	Low Level	High Level	Low Level	High Level	Low Level
		General Fact Finding						
32	B	Where do you see the company in ten years time?	•		•		•	
33	B	What is your organisation's core business?	•		•		•	
34	B	What is the annual turnover of your organisation?	•		•		•	
		Vendor Competition & Market Control						
35	Q3, P3.3	Which instrumentation suppliers do you use and how would you categorise each one? Large, institutional suppliers, good support, low responsivity Large, fragmented suppliers, poor support, high responsivity Small, dynamic suppliers, poor support, responsivity high->low	•	•	•	•		
36	Q1, P1.1	What issues affect the way in which you perform your role – i.e. what stops you doing your job effectively?	•	•	•	•	•	•
37	Q3, P3.3	Do you think that small suppliers of instruments are more responsive?	•	•	•	•		

Ref	Research Question/ Proposition	Technology Issue	Interviewee					
			End User		Customer		Supplier	
			High Level	Low Level	High Level	Low Level	High Level	Low Level
38	Q1, P1.1	How market focused is the development of your products?					•	•
39	Q1, P1.1	How are customer feedback and market projections incorporated into product development strategy?					•	•
40	Q1, P1.1	How do you monitor what your competitors are doing in terms of new product development?	•	•	•	•	•	•
41	Q3, P3.3	How market focused are your suppliers of instrumentation?	•	•	•	•		
42	Q3, P3.3	What are the disadvantages of your products compared to your competitors?					•	•
43	Q3, P3.3	What are the advantages of your products over your competitors?					•	•
44	Q3, P3.3	How does the range of products compare between these suppliers?	•	•	•	•		
45	Q3, P3.3	For any given range of products, how many competitors do you have?					•	•
46	Q3, P3.3	For any given type of instrument, what is the range of the number of suppliers?	•	•	•	•		
		Technology Push						
47	Q1, P1.1	Do you receive detailed specifications of what is required?					•	•
48	Q1, P1.1	Are these specifications normally what the user needs?					•	•
49	Q1, P1.1	Do you think briefings on latest technologies would be helpful?	•	•	•	•	•	•
50	Q1, P1.1	What are the issues associated with the capturing of end user requirements?			•	•	•	•
51	Q1, P1.1	Is there a process for eliciting end user requirements?			•	•	•	•
52	Q1, P1.1	How do you rate this process?			•	•	•	•
53	Q1, P1.1	How much is the development of technology driven by existing standards?	•	•	•	•	•	•
54	Q1, P1.1	Is this drive in the right direction?	•	•	•	•	•	•
55	Q1, P1.1	Do you think small instrument suppliers provide more innovative products than large suppliers?	•	•	•	•		
56	Q1, P1.1	What proportion of the equipment you purchase is for new types of measurement?	•	•	•	•		
57	Q1, P1.1	What proportion of the equipment you purchase is for instrumentation for new applications?	•	•	•	•		
		Technology Misuse						
58	Q1, P1.2	Are you aware of the full functionality of your instrumentation?		•		•		
59	Q1, P1.2	Have you ever known any unused functions to cause an instrument to fail? What were the consequences?		•		•		
60	Q1, P1.2	Do you receive training on new instrumentation systems? Is this training effective?		•		•		
61	Q1, P1.2	Are all the functions of their instruments fully utilised?		•		•		
62	Q1, P1.2	How much training do you give your clients about the instruments you supply?					•	•
63	Q1, P1.2	Should more effort be made to make your customer/users aware of the full capability of the equipment supplied?					•	•
		User Buy-in						
64	Q1, P1.1	Is the end user involved with your technology planning process?			•	•	•	•
65	Q1, P1.1	Do you feel you are involved with the instrumentation suppliers' technology planning process?	•	•				
66	Q1, P1.1	What information do you give the end user regarding any training needed to use the instrumentation?			•	•		
67	Q1, P1.1	What information do you give the end user regarding any training need to use your product?			•	•		
		Cost of Ownership						
68	Q3, P3.2	Do you take into account the cost of: Calibration? Training? Reliability? (Down time of plant, cost of time to sort out problem, etc.)	•	•	•	•		

Ref	Research Question/ Proposition	Technology Issue	Interviewee					
			End User		Customer		Supplier	
			High Level	Low Level	High Level	Low Level	High Level	Low Level
69	Q3, P3.2	How important to you is the ability to switch between suppliers? How easy do you find it?	•	•	•	•		
70	Q3, P3.2	How do you rate the level of support you receive?	•	•	•	•		
71	Q3, P3.2	How does the range of after sales services between your suppliers compare?	•	•	•	•		
72	Q3, P3.2	What level of after sales care do you offer?					•	•
73	Q3, P3.2	How important do you think after sales care is for your customers?					•	•
74	Q3, P3.2	How do you rate your needs for after sales support?	•	•	•	•		
		Lifecycle Mismatch						
75	Q2, P2.1	How do you plan for the delivery of the 'right' instrument when your process requires it?	•	•	•	•		
76	Q2, P2.1	How does the ease with which you can update instrumentation affect process improvement?	•	•	•	•		
77	Q2, P2.1	Are new instruments generally available when you need them?	•	•	•	•		
78	Q2, P2.1	How easy do you find this ability to upgrade your instrumentation?	•	•	•	•		
79	Q2, P2.1	What is your typical time to market for new products?					•	•
		Interface Compatibility and Profusion of Standards						
80	Q1, P1.3	Do you find these standards useful in your use of instruments?		•		•		•
81	Q1, P1.3	What instrumentation standards are you aware of?	•	•	•	•	•	•
82	Q1, P1.3	In what way do these standards aid or hinder the integration of equipment?		•		•		•
		Compatibility with Bespoke Systems						
83	Q1, P1.3	Do you provide single items of equipment or do you provide an integration process?					•	•
84	Q1, P1.3	Do you provide or are you interested in providing an integrated solution?					•	•
		Influence						
85	Q1, P1.1	What is the procurement process for purchasing the instruments you use?		•		•		
86	Q1, P1.1	What influence over the decision do you have?		•		•		
87	Q1, P1.1	How do you make your decision?		•		•		
88	Q1, P1.1	What trade offs do you need to make?		•		•		
89	Q1, P1.1	How do you affect decisions that are made – in particular with regard to the procurement of equipment?	•	•	•	•		
90	Q1, P1.1	How often do you find the right piece of equipment for the right price?		•		•		
91	Q1, P1.1	Are you aware of any suppliers that would assemble a system to meet your needs that would include integrating equipment from other suppliers?		•		•		
92	Q1, P1.1	Do you find you need to assembly and integrate the system from multiple suppliers?		•		•		
93	Q1, P1.1	How much do you spend on behalf of the company in supporting and maintaining this instrumentation (include calibration, training, supplier lock, liability and expectations)?	•	•	•	•		
		Impact on Bottom Line						
94	Q3, P3.1	What are the major variables that affect the business' performance?	•		•		•	
95	Q3, P3.1	How is this measured?	•		•		•	
96	Q3, P3.1	What problems are you aware of that cause problems with these variables and hence the business?	•		•		•	
		Where Does Technology Bite?						
97	Q1, P1.1	What process does the organisation go through to plan for technology?	•	•	•	•	•	•
98	Q3, P3.1	How import is the use of instrumentation in the way in which the product is used?	•	•	•	•		

Ref	Research Question/ Proposition	Technology Issue	Interviewee					
			End User		Customer		Supplier	
			High Level	Low Level	High Level	Low Level	High Level	Low Level
99	Q3, P3.1	What would happen if this instrumentation produced errors, failed or was unavailable?	•	•	•	•		
100	Q1, P1.1	Who decides how this is specified?	•	•	•	•		
101	Q1, P1.1	How much influence do you have over the way in which such equipment is developed?	•	•	•	•		
102	Q1, P1.1	Is this process applied to non-core activities as well, for example the instrumentation they use?	•	•	•	•		
103	Q1, P1.1	Do they believe this process is effective?	•	•	•	•		
104	Q1, P1.1	If not – what problems do they perceive exist?	•	•	•	•		
105	Q1, P1.1	How are these decisions made – i.e. market driven, technology driven?	•	•	•	•	•	•
106	Q1, P1.1	How much customer/end user input to this technology planning is there?			•	•	•	•
107	Q1, P1.1	Is this used to identify new technologies and to decide which ones the company should invest in?	•	•	•	•		
108	Q1, P1.1	Do you understand the technology involved in these non-core activities?	•	•	•	•		
109	Q3, P3.2	How much does the company spend on supporting and maintaining this instrumentation (include calibration, training, supplier lock, liability and expectations)?	•		•			
110	Q3, P3.2	How is such equipment procured – by your organisation or by your supplier?	•	•	•	•		
111	Q3, P3.2	How much does the company spend on the procurement of instrumentation?	•		•			

APPENDIX 6 INTERVIEW DATABASE

The screenshot shows the Microsoft Access application window titled "Microsoft Access - [Interviewee Details]". The interface includes a menu bar (File, Edit, View, Insert, Format, Records, Tools, Window, Help) and a toolbar with various icons for file operations, editing, and navigation.

The main window is divided into two panes. The left pane displays the "Interviewee" form, which contains the following fields and values:

- Interviewee ID: 48
- First Name: A.N.
- Surname: Other
- Position: Instrument User
- Company: Big Pharma Dot Com
- Company Address 1: Big Industries Estate
- Company Address 2:
- Town/City: UK Town
- County:
- Post Code:
- Telephone Number: 01 234 56789
- Fax Number: 01 234 98765
- Email Address: a.n.other@bigpharma.com
- Data Protection Form Received: 28/1/2002

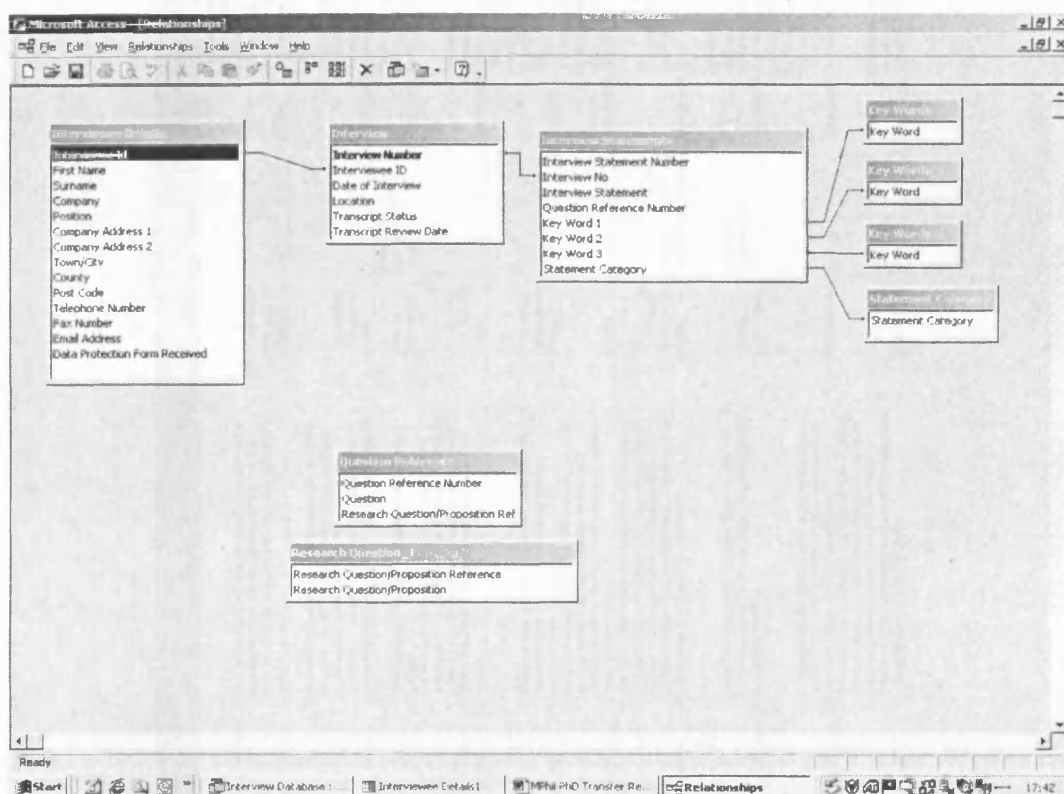
The right pane displays the "Interview" table, which contains two records:

Interview Number	Interviewee ID	Date of Interview	Location
50	48	26/1/2002	UK Town
(AutoNumber)	48		

Below the Interview table, the "Interview Statements" table is visible, showing two records:

Interview Statement Number	Interview No	Interview Statement	Interview Statement Key Word
1244	50	Interview statements entered here.	Background
1245	50	Each statement individually entered and categorised	Education/Training/Information

The status bar at the bottom indicates the current record position: "Record: 14 of 46" and "Interview Statement Number: 46".



APPENDIX 7 SAMPLE OF THE INTERVIEW DATA AND EXAMPLE OF THE REVIEWS

Interview Statement Number	Interview Topic	Interview Statement	Database Review First Iteration					Database Review Second Iteration					Implication On Model 3	Implication On Model 4	Implication On Model 5	Category
			Key Word 1	Key Word 2	Key Word 3	Statement Category	Issue 1	Issue 2	Issue 3	Implication On Model 1	Implication On Model 2	Implication On Model 3				
833		User technology roadmaps are usually focused on their core business and not on the development of new products. So instrumentation development roadmaps aren't seen.	Technology Management Tools			Problem	Technology Management - User technology roadmaps are usually focused on their core business and not on the development of new products. So instrumentation development roadmaps aren't seen.			No formal technology planning tools used						
86		Person X has provided support from the very top of the company. He saw the value achieved from the Shurlock's activity, but felt this must be made more systematic. Tech Dev was therefore created. Person X stated that it should be staffed with appropriate people.	Technology Management Tools			Background	Technology Management - value achieved from the Shurlock's activity, but felt this must be made more systematic.			Address ability	Address attitude					
401		What formal technology planning methods were used? - Are you involved in groups who are looking at future technologies? PF says yes - he is working closely with a task force that functions right across the organisation. However the level of visibility of company needs is 12 variable.	Market Awareness Tools	Technology Management Tools		Background	Technology Management - What formal technology planning methods were used? - PF says yes - he is working closely with a task force that functions right across the organisation.			Internal forum can facilitate knowledge exchange	Internal groupings can undertake concept studies					
760		Small suppliers company. People very motivated by the idea of innovation when they can see a specific purpose, so there are few examples of under-utilisation of available functions. There are some examples where the utility has been improved.	Technology Management Tools			Problem	Technology Management - Small suppliers company. People very motivated by the idea of innovation when they can see a specific purpose, so there are few examples of under-utilisation of available functions. There are some examples where the utility has been improved.			Capacity effects innovation	Backup - Small suppliers may wish to move into new markets or production for increased profits					
766		Company Y has a projected lifespan for an instrument. Company Y's core business is liquid handling, and since liquid handling is a key part of their business, the demand for Company Y's instrument line is a bell-curve.	Technology Management Tools			Background	Technology Management - Company Y has a projected lifespan for an instrument. Company Y's core business is liquid handling, and since liquid handling is a key part of their business, the demand for Company Y's instrument line is a bell-curve.			Economic trade-off between upgrade and new system	Address upgradability					
125		Large suppliers model innovation from smaller companies, select the most salient and incorporate in their product portfolio.	Market Awareness Tools	Technology Management Tools		Background	Technology Planning - The demand for new product over time is a bell-curve.	Awareness - Monitoring trends to identify core technologies	Vision - Supplier has identified core instrument technology	Address lifecycle issues						
221		Competitive tendering does generate some market pull, but there isn't much innovation for these proposals - it often comes down to who is the cheapest. Competitive tendering does generate some market pull, but there isn't much innovation for these proposals - it often comes down to who is the cheapest.	Market Awareness Tools			Background	Technology Planning - Large suppliers model innovation from smaller companies, select the most salient and incorporate in their product portfolio.			Large companies can acquire new ideas by buying small companies						
701		Competitive tendering does generate some market pull, but there isn't much innovation for these proposals - it often comes down to who is the cheapest. Competitive tendering does generate some market pull, but there isn't much innovation for these proposals - it often comes down to who is the cheapest.	Market Awareness Tools			Background	Technology Planning - Large suppliers model innovation from smaller companies, select the most salient and incorporate in their product portfolio.			Competitive tendering can stifle innovation						
976		Stephane Wong is a leading proponent in this area (and was the first to join Tech Dev in 1998).	Technology Push			Aspiration	Technology Push - example the use of micro chemistry compounds created on scratches on glass.									
90																

APPENDIX 8 METZ FIVE BEST PRACTICES OF TECHNOLOGY PLANNING/BUSINESS PLANNING MODELLING EXAMPLE

The Metz Five Best Practices model was selected for this example to avoid repetition. This is due to the majority of the Metz model being covered by the Technology Planning and Management Lifecycle Model described in chapter 5 and hence the following models were not required. Where the Technology Planning and Management Lifecycle Model covers Metz's Best Practices, this is indicated on the model and discussed in chapter 5.

To aid the understanding of the Metz Best Practice Model text descriptions have been added.

The class diagram, **Error! Reference source not found.**Figure A8-1, shows Metz five best practices being made up of: Management Commitment, Structured Technology Plan, Organise For Technology, Foster Involvement Between Departments, and Business Unit Accountability.

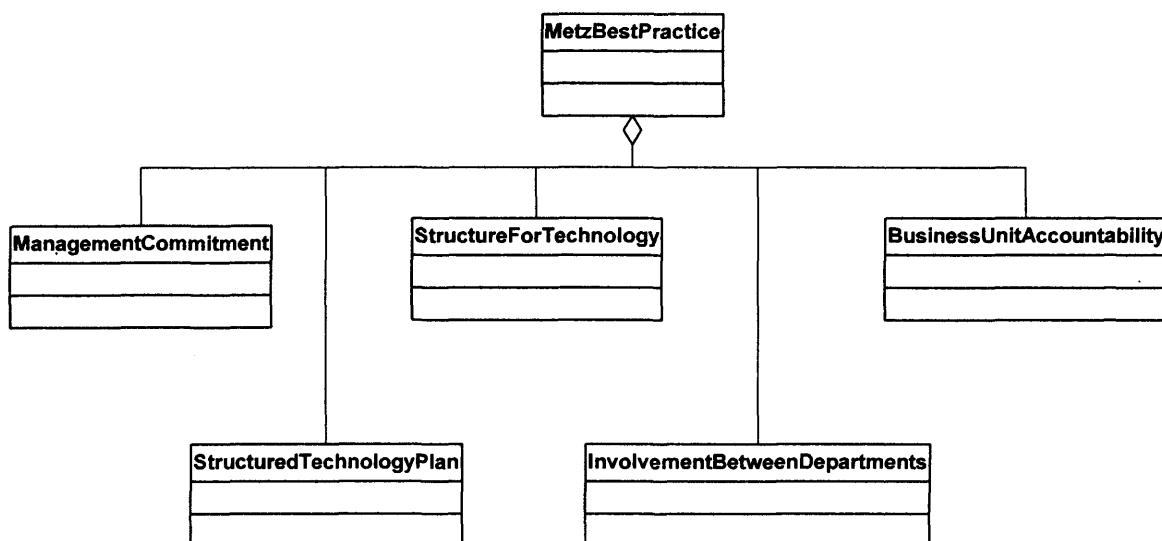


Figure A8-1 Metz Best Practice Class Diagram

The five best practices follow a certain degree of order and hence are shown as a series of sequential activities in Figure A8-2. There will be, however, some concurrency and iteration

between the activities which is not easily shown within the syntax of UML. This constraint has been encountered on other business process models (Cowper et al, 2004).

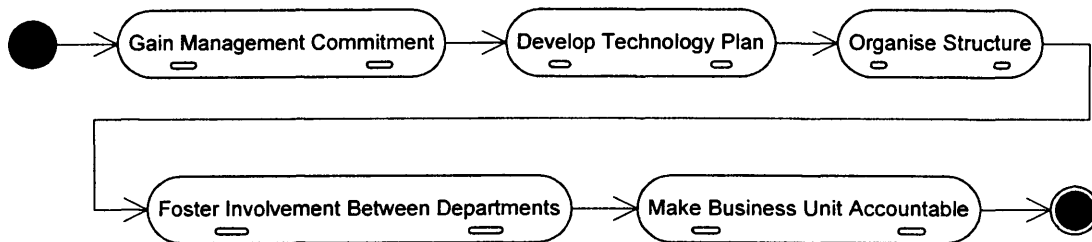


Figure A8-2 Metz Best Practice Activity Diagram

Taking each one of the five best practices from Figure A8-2 in turn, Figure A8-3 shows the activity diagram for gaining management commitment, Metz first Best Practice. Gaining this commitment involves senior management assessing the reasons behind technology development and ensuring there is a business case for the investment required. Figure A8-4 shows the associated class diagram for gaining management commitment and Figure A8-5 shows the change in state of senior management from not committed to committed to technology planning.

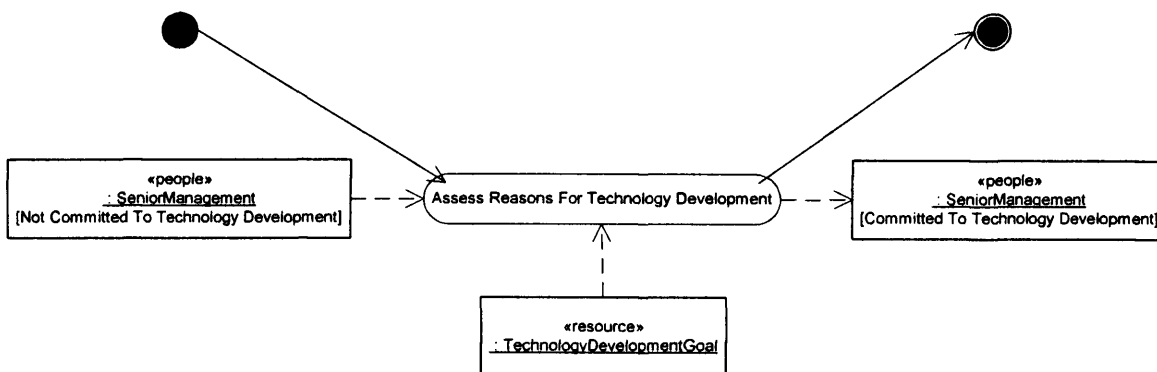


Figure A8-3 Gain Management Commitment Activity Diagram

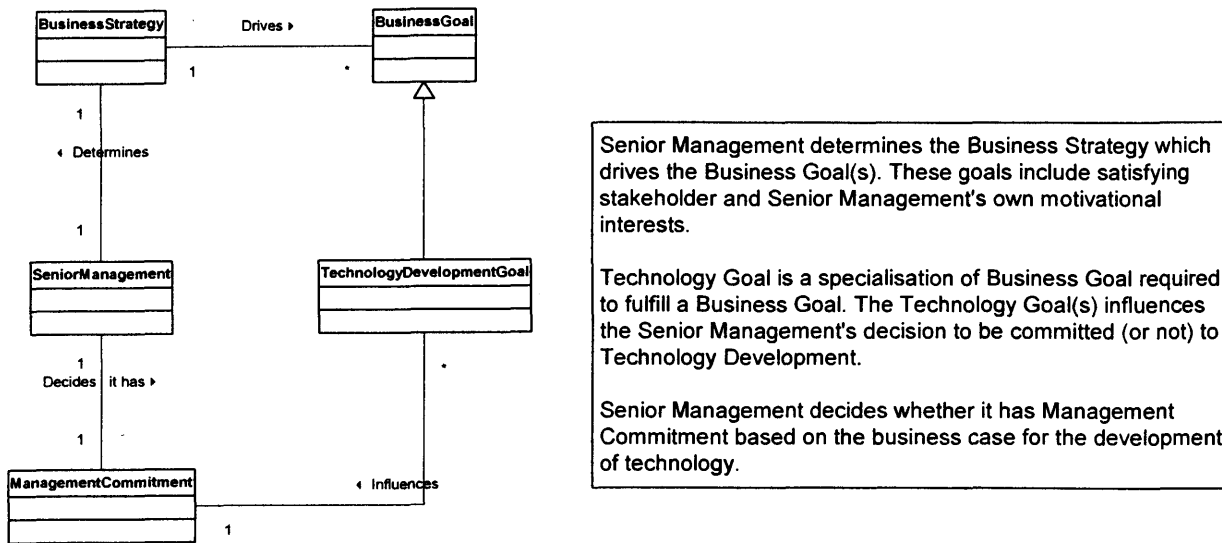


Figure A8-4 Management Commitment Class Diagram

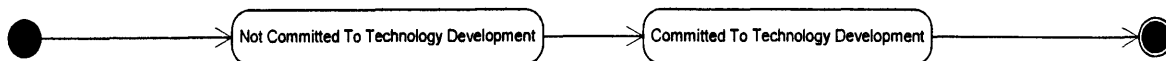
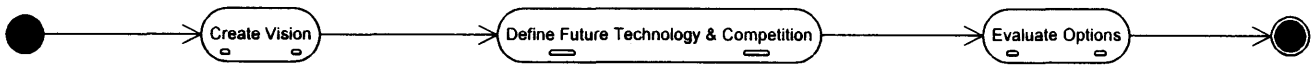


Figure A8-5 Senior Management State Chart Diagram

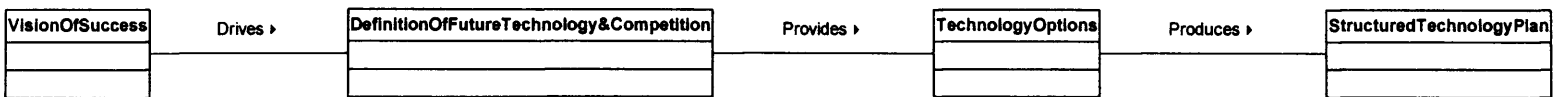
Figure A8-6 and Figure A8-7 show the development of a technology plan activity and class diagrams respectively. The development of a technology plan, the second of Metz Best Practices, consists of creating a vision, defining future technology and future competition and then evaluating the options. Each of these activities is shown as a composite activity. Composite activities are activities which are made up from another activity diagram. This allows processes to be made hierarchical using a nested set of activity diagrams.



The Structured Technology Plan is generated from a 3 Step Process.

The 3 Step Process creates a Vision, defines Future Technology and Competition, and evaluates the Technology Options.

Figure A8-6 Develop Technology Plan Activity Diagram



The process to generate a Structured Technology Plan starts with the Vision of Success which is generated and communicated by Senior Management (see creation of vision). This vision drives the company to Define the Future Technology and Competition. This definition provides the Technology Options which are then evaluated. The selected technology options forms the basis for the structured technology plan.

Figure A8-7 Structured Technology Plan Class Diagram

The creation of the vision sub-process activity diagram is shown in Figure A8-8 with its associated class diagram in Figure A8-9. The vision is created from business and technology development goals and then communicated to the organisation. This transition of the vision from being created to being communicated is shown in the vision state chart diagram, Figure A8-10.

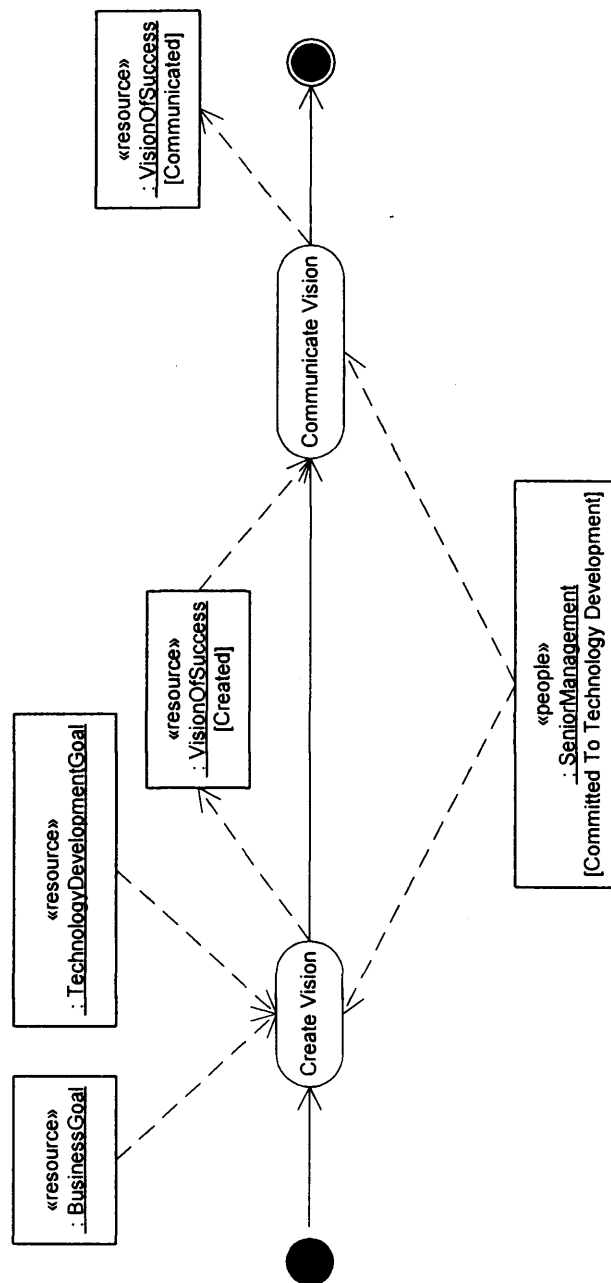
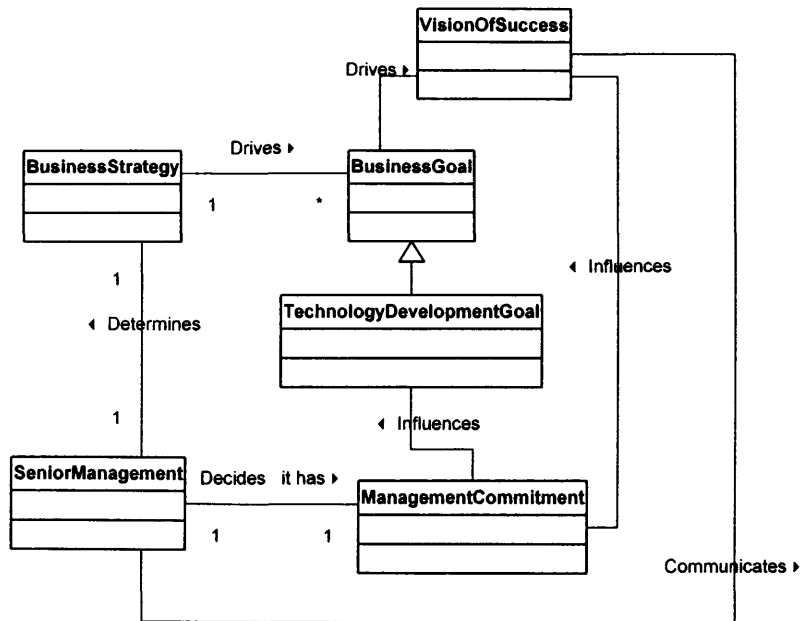


Figure A8-8 Creation Of Vision Activity Diagram

Figure A8-9 Creation Of Vision Class Diagram



Senior Management determines the Business Strategy that drives the Business Goal(s). The Business Goal(s) drives the Vision of Success.

A specialisation of the business goal(s) is the Technology Development Goal(s). These influence Senior Management's Commitment to technology development. This Management Commitment influences the Creation of Vision.

A Vision of Success is created. Senior Management communicate this vision.

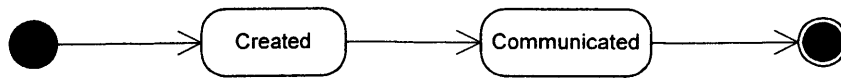


Figure A8-10 Vision State Chart Diagram

The definition of future technology and future competition uses inputs from a wide range of sources, see Figure A8-11 for activity diagram and Figure A8-12 for associated class diagram. These sources include the various functions across the business providing information on: new production processes, new products, new technology, future competition, etc.

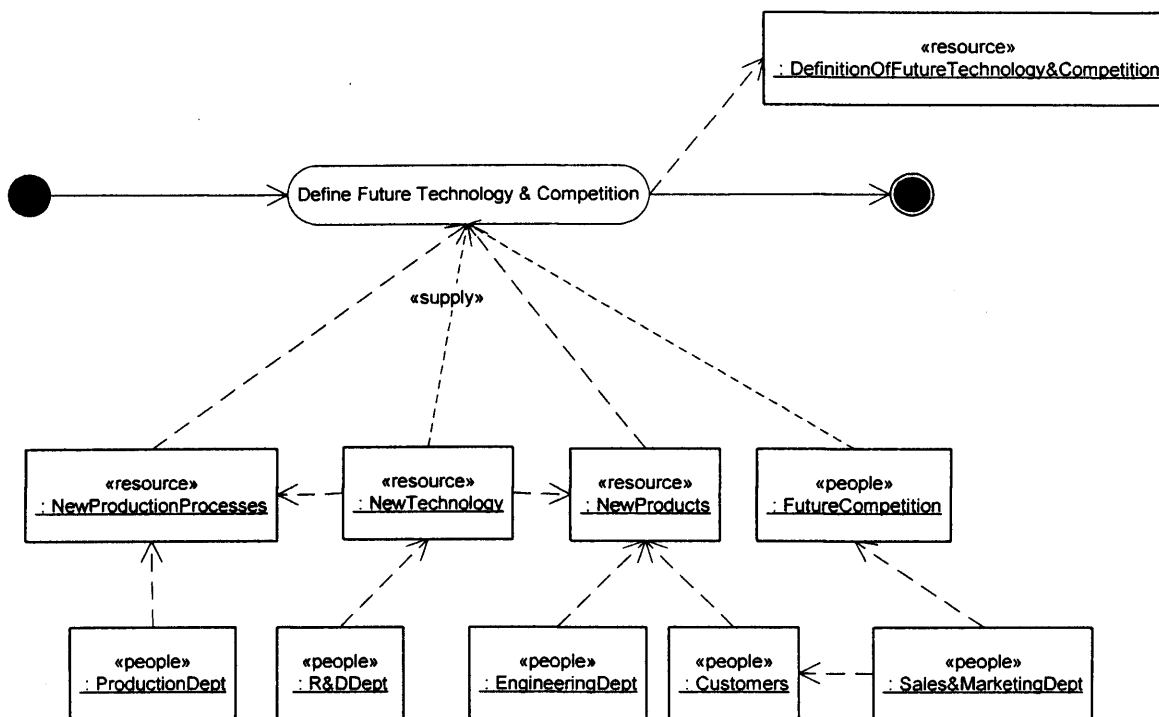
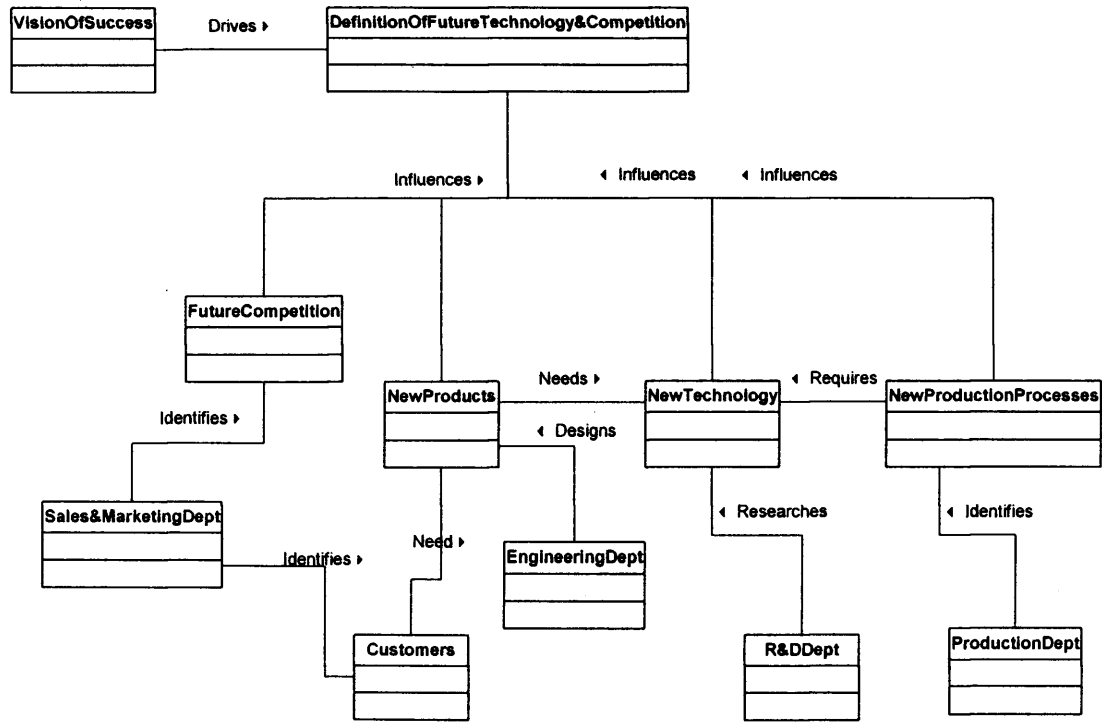


Figure A8-11 Definition Of Future Technology Activity Diagram



The Vision of Success drives the process to Define Future Technology and Competition.

The Sales & Marketing Dept identifies Future Competition. This Future Competition influences the Definition of Future Technology.

The Sales & Marketing Dept identifies Customers who need New Products. These New Products are designed by Engineering Dept and requires New Technology.

Production Dept identifies New Production Processes which require New Technology.

The New Technology for both New Products and New Production Processes is researched by the R&D Dept.

The New Products, New Production Processes and New Technology influences the Definition of Future Technology.

The process to Define Future Technology and Competition produces a Definition of Future Technology.

Figure A8-12 Definition Of Future Technology Class Diagram

The evaluation of technology options takes the data gathered from defining future technology and future customers to inform the decision making process (e.g. cost benefit analysis), see Figure A8-13 and Figure A8-14 for the activity and associated class diagrams.

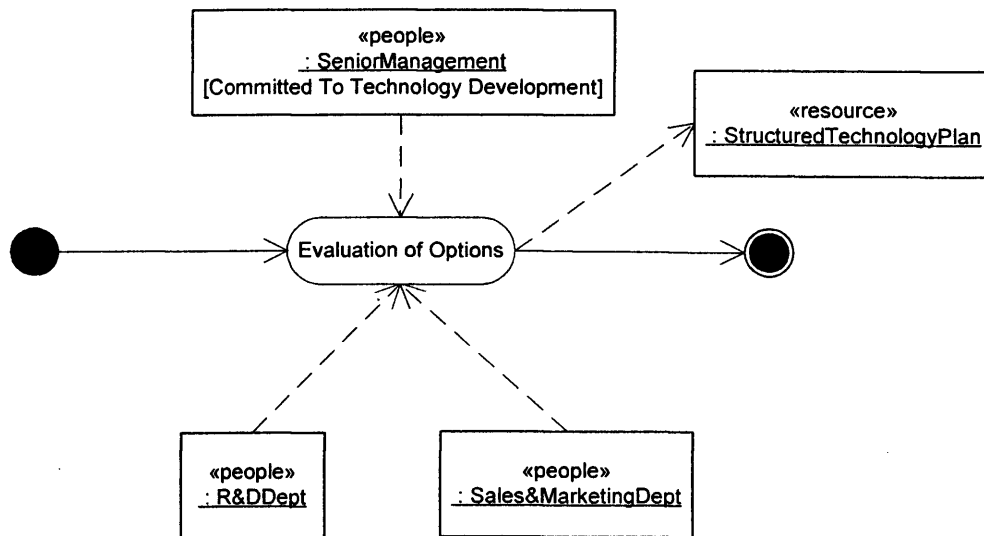
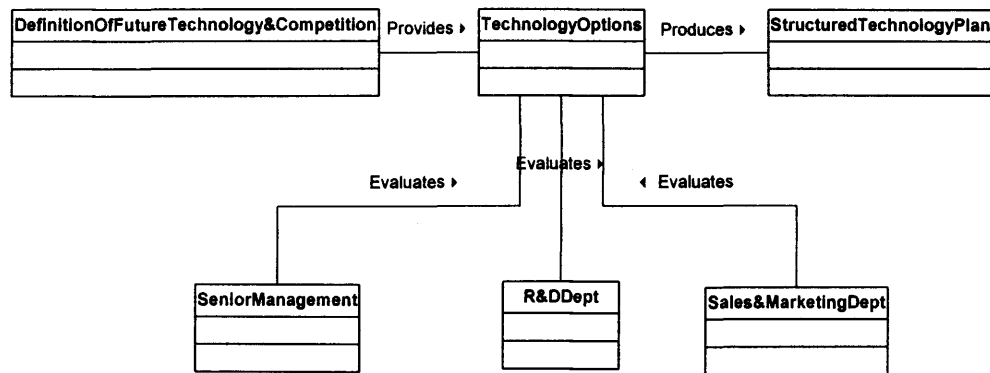


Figure A8-13 Evaluate Options Activity Diagram



The Definition of Future Technology is used to evaluate the Tehnology Options.

Senior Management, Sales and Marketing Dept and the R&D Dept all provide input to evaluating the options.

The Evaluation of Options Process produces the Technology Plan.

Figure A8-14 Evaluate Options Class Diagram

Metz third Best Practice is to organise the structure for technology planning, see Figure A8-15 for activity and Figure A8-16 for class diagrams. Organising for technology planning aims to transform the organisation so that it supports technology planning, see Figure A8-17 for associate state chart diagram. This transformation requires management commitment and may also require a cultural change to the organisation.

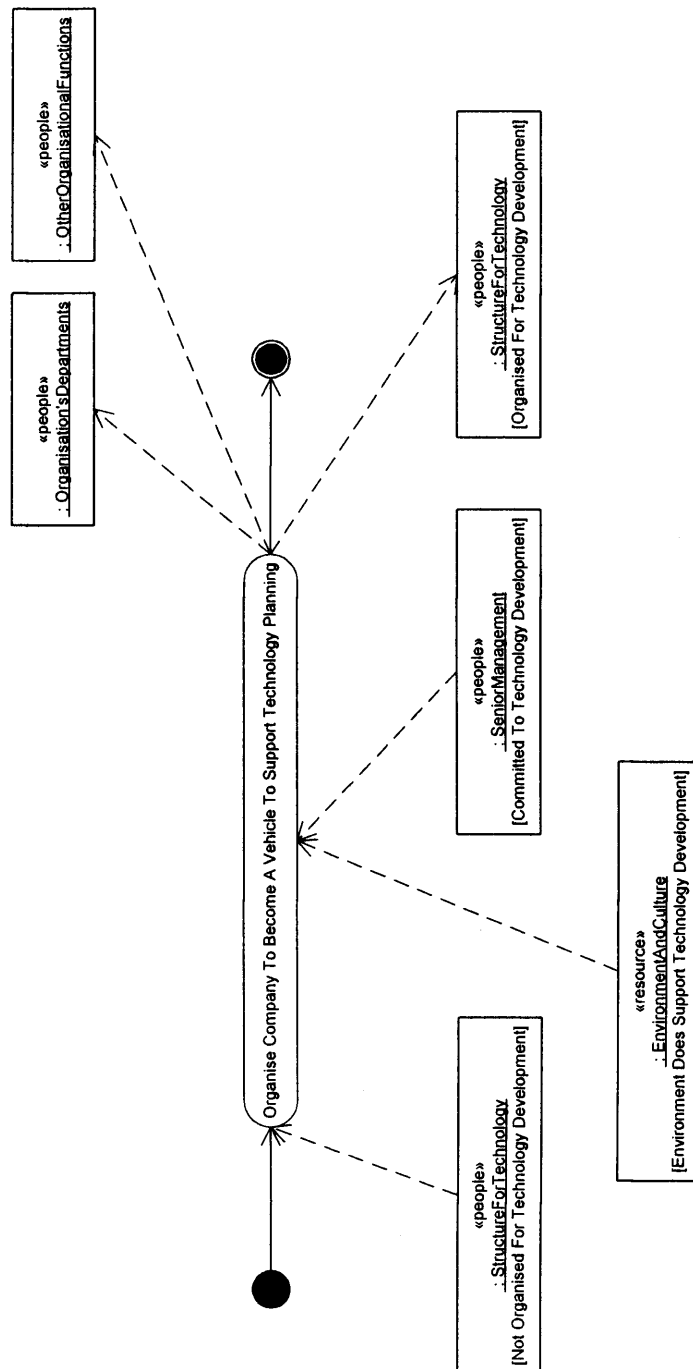


Figure A8-15 Organise Structure Activity Diagram

Senior Management facilitates an Environment and Culture that supports Technology Development.

Senior Management organises the Organisation's Structure to support Technology Development. This includes ALL organisational functions.

The Environment and Culture which supports Technology Development influences the Organisation's Departments.

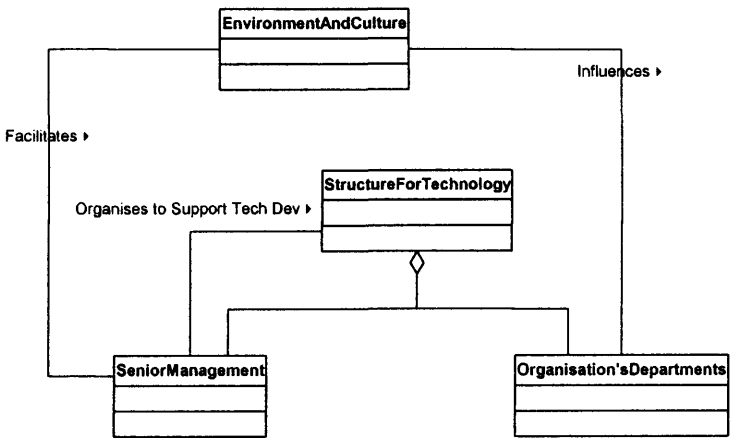


Figure A8-16 Organise Structure Class Diagram



Figure A8-17 Organise Structure State Chart Diagram

The fourth Best Practice reinforces the structural and cultural changes to the organisation by fostering involvement between departments in order to ensure buy-in to the technology development process by the whole organisation. An environment and culture for technology planning is created, see Figure A8-18 for state chart, Figure A8-20 for activity and Figure A8-21 for class diagrams. Creating this environment and culture requires management commitment to provide the required resources and a structured technology plan to give direction.

The selection of technology projects involves inputs from all departments to ensure the whole organisation is involved with the process. Finally the projects are delivered by collaborating teams from the organisation. Figure A8-19 project selection state chart diagram shows the state transition of projects through the process.



Figure A8-18 Organisation's Environment State Chart Diagram

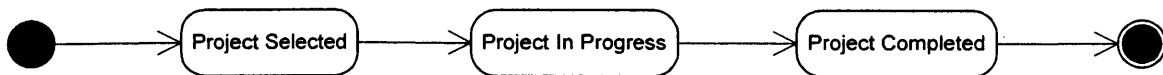


Figure A8-19 Project Selection State Chart Diagram

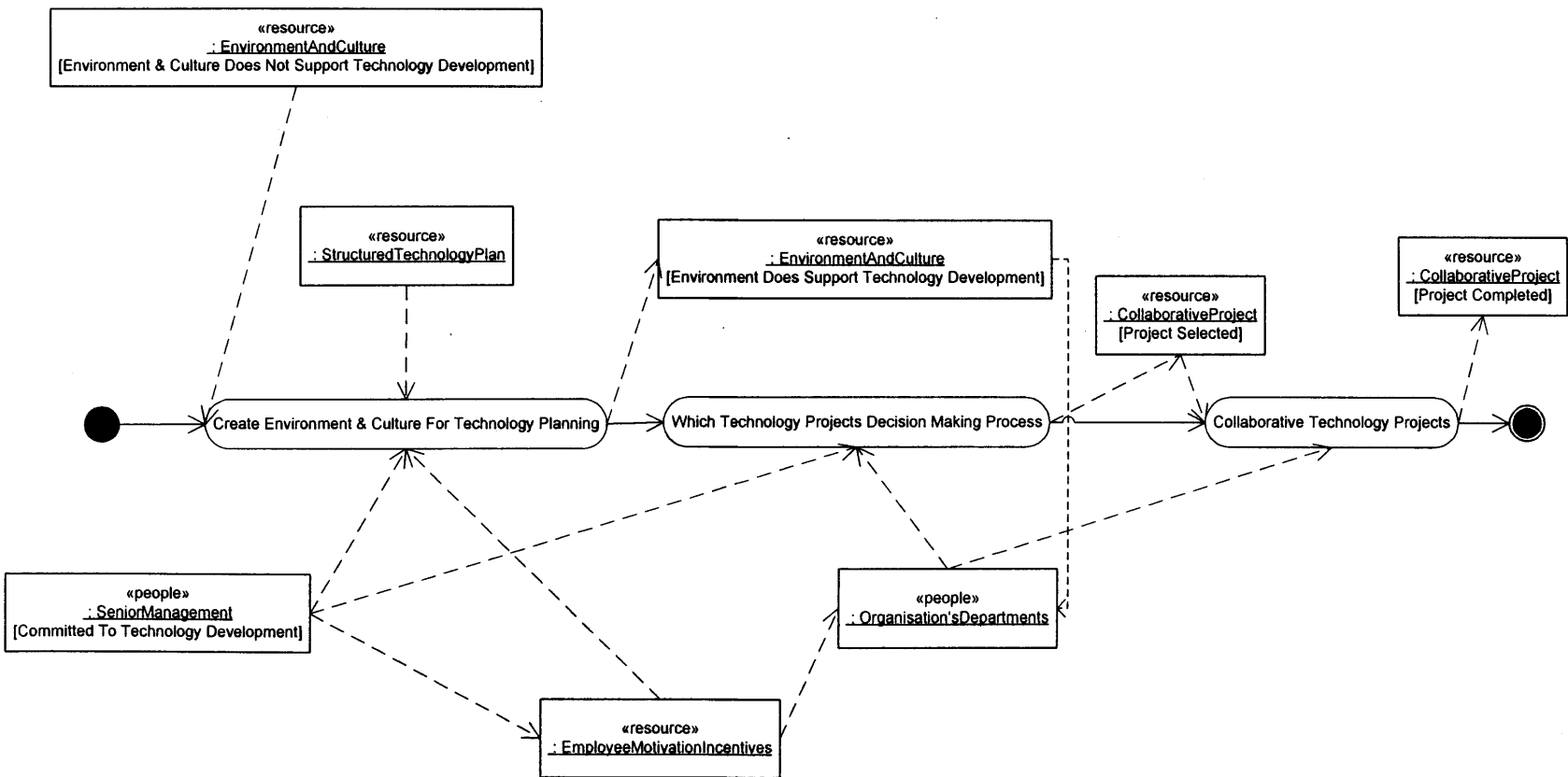
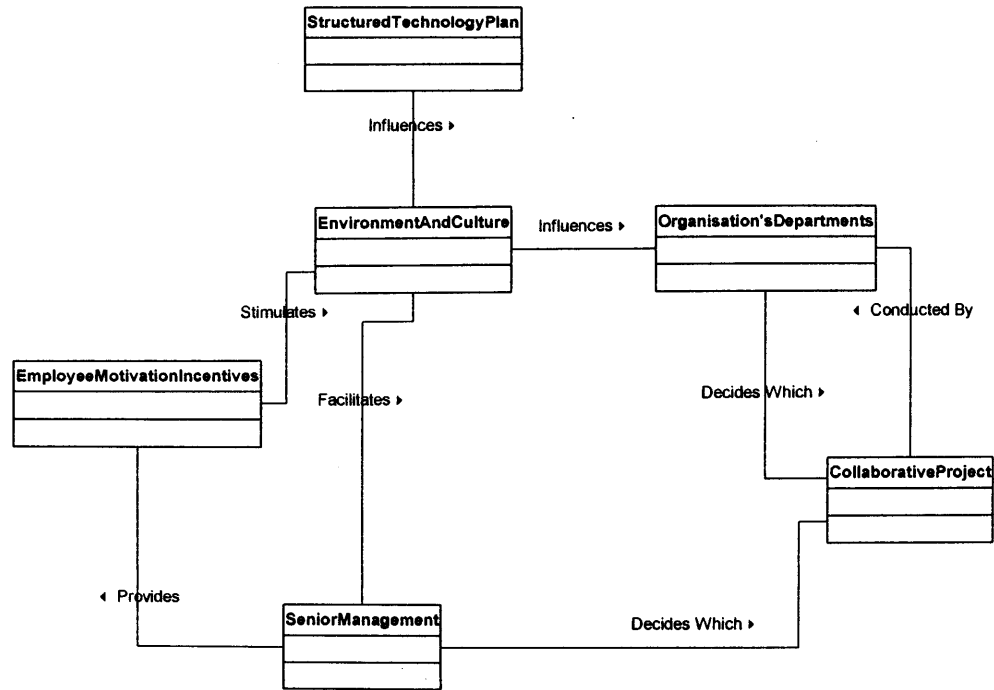


Figure A8-20 Foster Involvement Between Departments Activity Diagram

Figure A8-21 Foster Involvement Between Departments Class Diagram



Senior Management provides Motivational Incentives which stimulates the Environment and Culture for technology development. Senior Management also facilitates a positive Environment and Culture which is also influenced by the technology plan.

This Environment and Culture influences the Organisation's Departments who are involved, along with Senior Management in the Decision Making Process. They decide what Collaborative Technology Development Projects should be conducted.

These Collaborative Projects are conducted by the Organisation's Departments.

The last one of Metz Best Practices is to make business units accountable for their technology development. Figure A8-23 activity diagram shows the process for holding business units accountable as: defining the measures and targets (see Figure A8-22 state chart diagram), creating an internal market, putting the measures in place and holding the business units accountable for their performance. Figure A8-24 shows the associated class diagram and Figure A8-25 the business goals class diagram which is used as an input to the process.

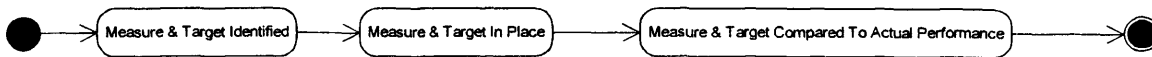


Figure A8-22 Measures And Targets State Chart Diagram

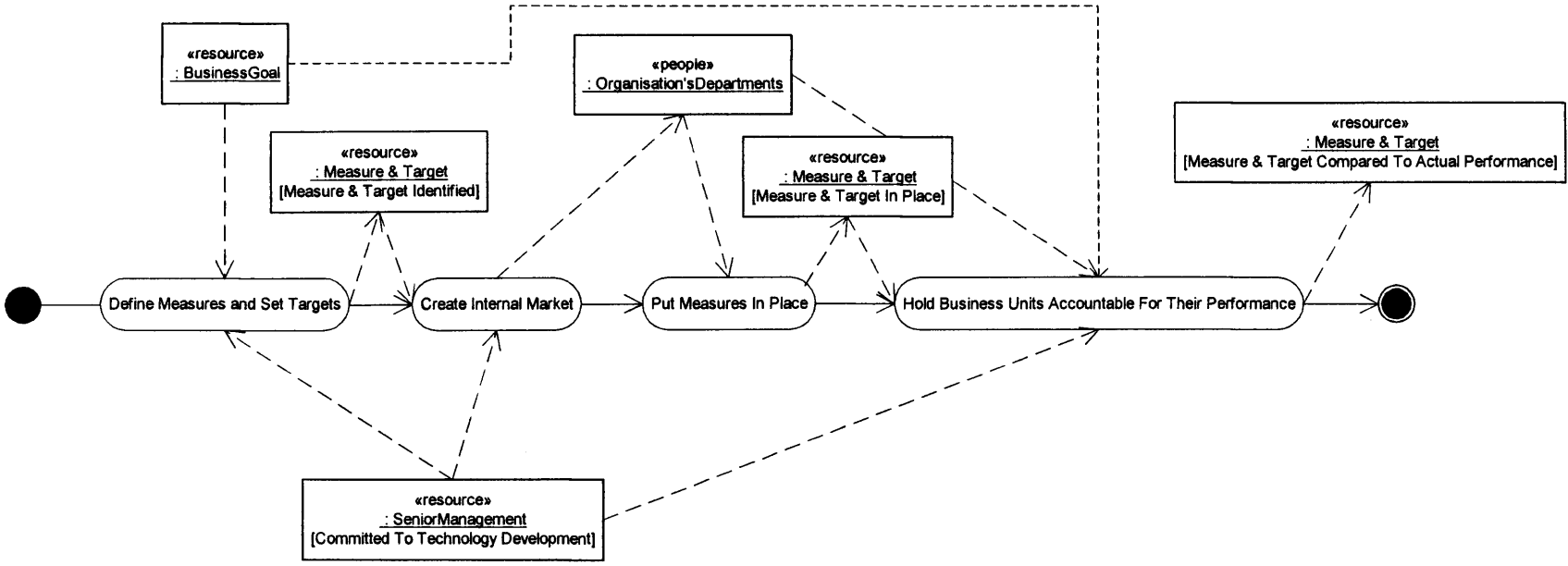
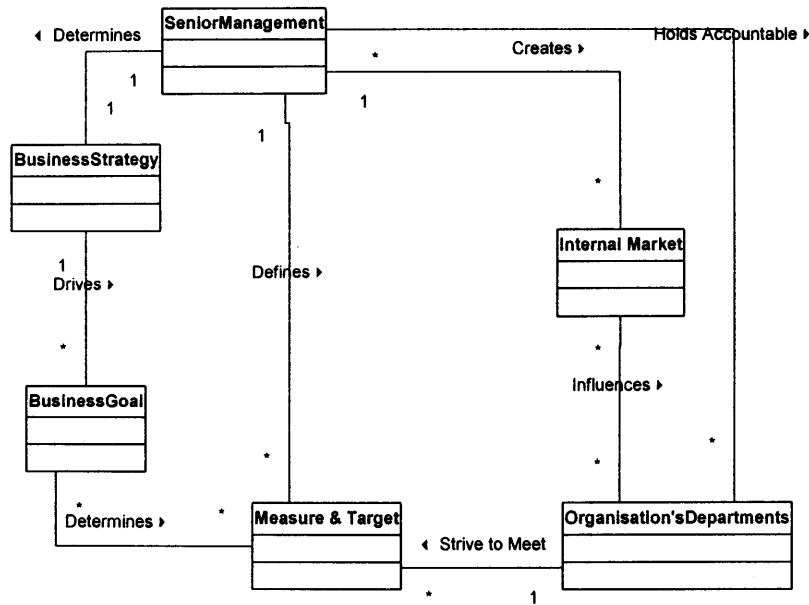


Figure A8-23 Make Units Accountable Activity Diagram

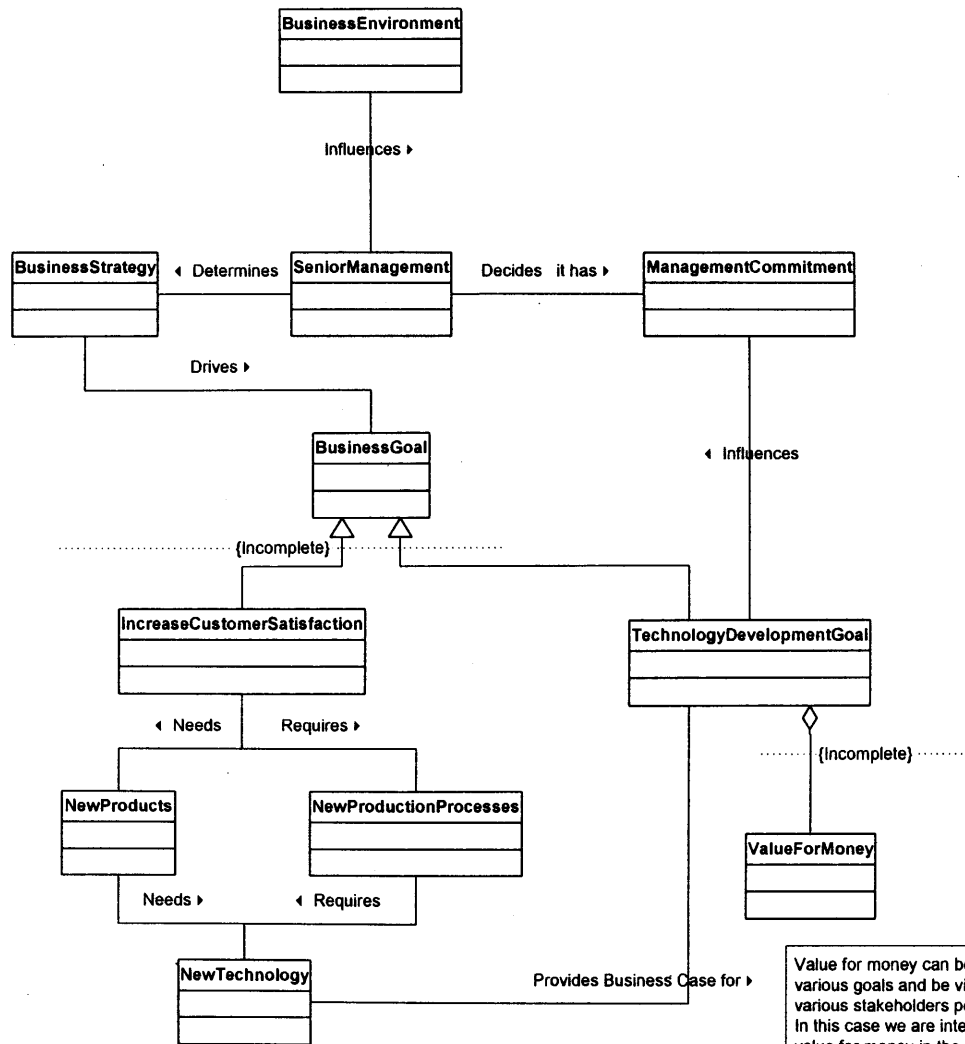
Figure A8-24 Make Units Accountable Class Diagram



Senior Management determines the Business Strategy which in turn drives the Business Goal(s). These determine the Measures and Targets. Senior Management defines these Measures and Targets.

Senior Management creates an Internal Market which influences how the Organisation's Departments interact.

The Organisation's Departments put in place the Measures and strive to meet the Targets. Senior Management hold them accountable against their performance measures and value for money.



The Business Environment influences Senior Management when determining the Business Strategy. The Business Strategy drives the Business Goal(s).

The Technology Development Goal(s) is a specialisation of a Business Goal that influences Senior Management's Commitment to technology development. The requirement for New Technology provides the business case for the Technology Development Goal(s).

One of the Technology Development Goals identified by Metz is Value for Money. In this context it refers to the value to the company of the technology developed and is one of the measures used to hold business units accountable.

The Business Goals includes Increased Customer Satisfaction. This list is incomplete.

The goal of Increased Customer Satisfaction requires New Production Processes and needs New Products. These both in turn require New Technology.

Value for money can be applied to various goals and be viewed from various stakeholders perspective. In this case we are interested in the value for money in the development of technology and viewed from the company's perspective.

Figure A8-25 Business Goals Class Diagram

APPENDIX 9 TECHNOLOGY PLANNING WORKSHOP QUESTIONNAIRE AND RESULTS

Technology Planning Workshop at (*Organisation*) Questionnaire

Name:.....

Date:.....

Please circle only one number per answer!

Q1. To what extent does technology affect your organisation's activities?

Not At All	Hardly	Sometimes	Usually	Significantly
1	2	3	4	5

2. How do you rate (*Organisation's*) ability to bring technologies forward when they're needed?

Extremely Poor	Poor	Moderate	Good	Excellent
1	2	3	4	5

Q3. How important do you think technology planning is for the future of (*Organisation*)?

Very Unimportant	Fairly Unimportant	Neither Important Nor Unimportant	Fairly Important	Very Important
1	2	3	4	5

Q4. How much involvement do you have in technology planning within (*Organisation*)?

None	A Little	Modest	A Lot	Majority Of The Time
1	2	3	4	5

Q5. Do you feel you have enough opportunity to get involved in technology planning? Yes No (Please circle)

Q6. Do you come across technology plans? Yes No (Please circle)

If so, how well do you think they're implemented?

Rarely Implemented	Objectives Not Usually Met	Objectives Sometimes Met	Objectives Usually Met	Objectives Always Met
1	2	3	4	5

Continued...

Q7. Which, if any, formal technology planning tools do you use?

(If you do not use any tools, please write none and go on to Q9, else please list and complete Q8)

.....

.....

.....

Q8.If you do use formal technology planning tool(s):

a) How would you rate the usability of these tool(s)?

Difficult To Use	Fairly Difficult	Neither Difficult Nor Easy To Use	Fairly Easy	Easy To Use
1	2	3	4	5

b) How would you rate the benefit of using these tool(s) to make technology investment decisions?

Very Little Benefit	Fairly Little Benefit	Some Benefit	Fairly Large Benefit	Very Large Benefit
1	2	3	4	5

c) How useful have you found technology planning exercises you have completed?

Very Little Use	Fairly Little Use	Of Some Use	Fairly Useful	Very Useful
1	2	3	4	5

d) Have technology planning exercises identified technologies you would not have otherwise considered?

Yes No (Please circle)

Q9. If you do not use formal technology planning tools, what is the main reason for this?

.....

.....

.....

End.

Figure A9 – 1 MSSL Technology Planning Workshop Questionnaire Responses

Name	Question 1 Workshop		Question 2 Workshop		Question 3 Workshop		Question 4 Workshop		Question 5 Workshop		Question 6 Workshop		Question 8a Workshop		Question 8b Workshop		Question 8c Workshop		Question Worksho
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1
Delegate 1	5	5	4	4	5	5	3	3	Y	Y	Y3	N	-	-	-	-	-	-	-
Delegate 2	5	5	3	4	5	5	3	3	N	N	Y3	Y3	4	-	5	-	5	-	Y
Delegate 3	5	-	3	-	5	-	3	-	N	-	N3	-	-	-	-	-	-	-	-
Delegate 4	5	5	4	4	5	5	2	3	Y	Y	Y4	N	-	-	-	-	-	-	-
Question 7: (Not all the delegates completed this question)										Question 9: (Again not all the delegates completed this question)									
Delegate 1 Before: None Delegate 1 After: None Delegate 2 Before: So far, Cambridge Fast-Start Technology Road Mapping Delegate 2 After: None Delegate 3 Before: None Delegate 4: Before None										Delegate 1 Before: I didn't know they existed! Delegate 1 After: I don't know any Delegate 2 After: Spartan involvement with the process (mine tends to be across a number of organisations, but of a shallow nature). Delegate 3 Before: Not aware of any Delegate 4 Before: Never been exposed to them. Delegate 4 After: Don't know any									

Name	Question 1		Question 2		Question 3		Question 4		Question 5		Question 6		Question 8a		Question 8b		Question 8c		Question 8d	
	Workshop		Workshop		Workshop		Workshop		Workshop		Workshop		Workshop		Workshop		Workshop		Workshop	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
Delegate 1	5	5	3	4	4	4	3	2	N	N	N	N	-	3	-	3	-	4	-	N
Delegate 2	4	4	4	4	4	4	3	3	Y	Y	N	N	-	-	-	-	-	-	-	-
Delegate 3	5		3		5		3		Y		Y 3		-		-		-		-	
Delegate 4	5	5	4	3	5	5	2	3	N	N	N	N	-	-	-	-	-	-	-	-
Delegate 5	4		4		5		4		N		Y 3		-		-		-		-	
Delegate 6		5		3		4		4		Y	N		-		-		-		-	

Question 7: (Not all the delegates completed this question)	Question 9: (Again not all the delegates completed this question)
<p>Delegate 1 Before: No formal tools, often 'working parties' – spread sheets, visio, etc. Some use of Discrete Event Simulation</p> <p>Delegate 1 After: Simul8, Process flow analysis, TRIZ (once!)</p> <p>Delegate 2 Before: No formal tools</p> <p>Delegate 4 Before: No formal tools</p> <p>Delegate 5 Before: None</p>	<p>Delegate 1 Before: Often rapid response times preclude time for such formalities.</p> <p>Delegate 2 Before: Ignorance of formal tools. Doubts over applicability.</p> <p>Delegate 3 Before: To my knowledge the number and diversity of disciplines within a company such as organisation 1 means that we don't have a 'structured' way of defining and using these tools.</p> <p>Delegate 4 Before: Ignorance</p> <p>Delegate 5 Before: None available</p> <p>Delegate 6 After: No involvement in formal structure for technology planning.</p>

Delegate Feedback

The results of the delegate feedback questionnaire were as follows:

Overall Summary:

Overall the workshop was well received. However, there were not many new ground breaking ideas.

Results of the feedback questionnaire:

1. Did the course meet the stated objectives?			
Not at all	Partly	Mostly 4	Completely
2. How do you rate the teaching approach used?			
Poor	Adequate	Good 3	Excellent 1
3. To what extent do you feel you have learned from the event?			
Nothing	A Little 1	A Good Deal 3	A Lot
4. How do you rate the course management and administration?			
Poor	Adequate 1	Good 2	Excellent 1
5. How do you rate the course handout material?			
Poor	Adequate 2	Good 2	Excellent

Figure A9 – 3 Organisation 1 Technology Planning Workshop Delegate Feedback

APPENDIX 10 MSSL TECHNOLOGY PLANNING WORKSHOP RESULTS

Solar Physics Workshop: Technology Evaluation - MSSL Scientists

MSSL Scientists

	Attributes											
	Science	Publicity	Tech Transfer	Training	Kudos	Opportunities for Research	Data	Facilities to Use	Teaching	Money	R&E	Technology
Weight	1	0.5	0.1	0.1	0.5	1	1	1	0.7	0.8	1	0.3
System	0.9	0.7	0.3	0.3	0.8	0.8	0.9	0.9	0.9	0.7	0.8	0.5
System1	0.8	0.7	0.7	0.7	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.3
System2												
System3												
System4												
System5												
System6												

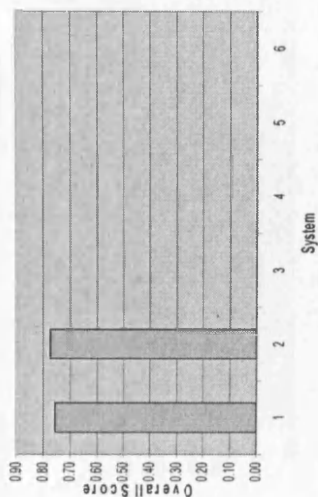


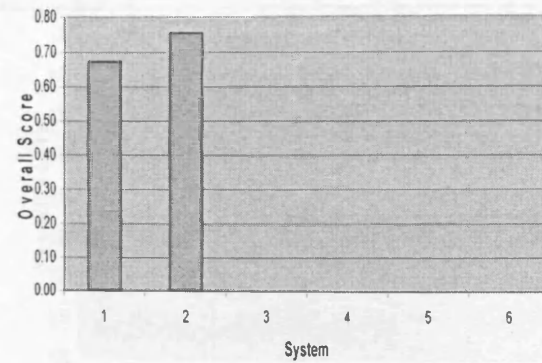
Table A10 – 1 MSSL Scientists' Requirements Rating

Solar Physics Workshop: Technology Evaluation - MSSL

MSSL

Table A10 – 2 MSSL's Requirements Rating

	Attributes																		
	Science	Publicity	Tech Transfer	Training	Kudos	Opportunities for Research	Data	Facilities to Use	Teaching	Money	RAE	Technology	Instruments	Excitement	Interest	National Pride	Direction to Their Programmes	Opportunity to Influence the Bigger Picture	Jobs
Weight	0.9	0.6	0.7	0.5	0.6	0.9	0.8	0.8	0.8	0.9	1	0.7	0.4	0.5	0.5	0.4	0.3	0.7	0.7
System	Scores																		
	System1	System2	System3	System4	System5	System6	System1	System2	System3	System4	System5	System6	System1	System2	System3	System4	System5	System6	System1
System1	0.9	0.7	0.3	0.3	0.8	0.8	0.9	0.9	0.9	0.7	0.8	0.5	0.5	0.9	0.9	0.7	0.5	0.5	0.5
System2	0.8	0.7	0.7	0.7	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.3	0.9	0.9	0.9	0.3	0.3	0.8
System3																			
System4																			
System5																			
System6																			



Solar Physics Workshop: Technology Evaluation - Solar Community

Solar Community

	Attributes																		
	Science	Publicity	Tech Transfer	Training	Kudos	Opportunities for Research	Data	Facilities to Use	Teaching	Money	RAE	Technology	Instruments	Excitement	Interest	National Pride	Direction to Their Programmes	Opportunity to Influence the Bigger Picture	Jobs
Weight	1	0.6	0.1	0.1	0.5	1	1	1	0.3	0.8	0.8	0.3	0.2	0.5	0.8	0.6	0.5	0.7	0.3
System	Scores																		
System1	0.9	0.7	0.3	0.3	0.8	0.8	0.9	0.9	0.9	0.7	0.8	0.5	0.5	0.9	0.9	0.7	0.5	0.5	0.7
System2	0.8	0.7	0.7	0.7	0.9	0.9	0.8	0.9	0.9	0.7	0.9	0.9	0.3	0.9	0.9	0.9	0.3	0.3	0.7
System3																			
System4																			
System5																			
System6																			

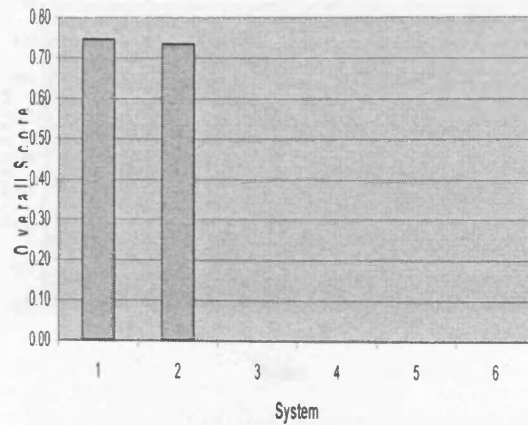


Table A10 – 3 Solar Community's Requirements Rating

Solar Physics Workshop: Technology Evaluation - Space Plasma Community

Attributes																			
	Science	Publicity	Tech Transfer	Training	Kudos	Opportunities for Research	Data	Facilities to Use	Teaching	Money	RAE	Technology	Instruments	Excitement	Interest	National Pride	Direction to Their Programmes	Opportunity to Influence the Bigger Picture	Jobs
Weight	1	0.6	0.1	0.1	0.5	1	1	1	0.3	0.8	0.8	0.3	0.2	0.5	0.8	0.6	0.5	0.7	0.3
System	Scores																		
System1	0.8	0.7	0.3	0.3	0.8	0.8	0.9	0.9	0.9	0.7	0.8	0.5	0.5	0.9	0.9	0.7	0.5	0.5	0.7
System2	0.9	0.7	0.7	0.7	0.9	0.9	0.8	0.9	0.9	0.7	0.9	0.9	0.3	0.9	0.9	0.9	0.3	0.3	0.7
System3																			
System4																			
System5																			
System6																			

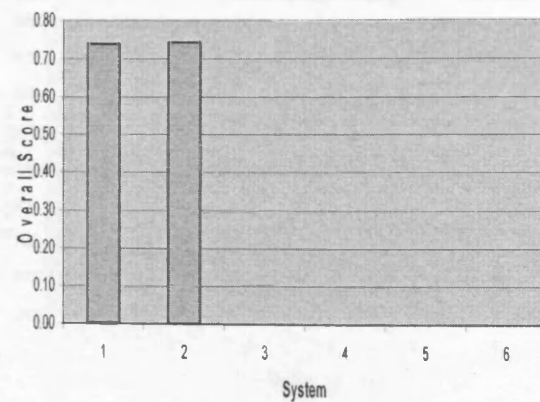


Table A10 – 4 Space Plasma's Requirements Rating

Solar Physics Workshop: Technology Evaluation - Space Agencies

Space Agencies

	Attributes																		
	Science	Publicity	Tech Transfer	Training	Kudos	Opportunities for Research	Data	Facilities to Use	Teaching	Money	RAE	Technology	Instruments	Excitement	Interest	National Pride	Direction to Their Programmes	Opportunity to Influence the Bigger Picture	Jobs
Weight	0.6	0.9	0.8	0.5	1	0.7	0.7	0.7	0.2	0.9	0.1	0.8	0.6	0.6	0.7	0.8	0.7	0.7	0.5
System	Scores																		
	System1	System2	System3	System4	System5	System6	System1	System2	System3	System4	System5	System6	System1	System2	System3	System4	System5	System6	System1
System1	0.9	0.7	0.3	0.3	0.8	0.8	0.9	0.9	0.9	0.5	0.8	0.5	0.5	0.9	0.9	0.7	0.5	0.5	0.7
System2	0.8	0.7	0.7	0.7	0.9	0.9	0.8	0.9	0.9	0.8	0.9	0.9	0.3	0.9	0.9	0.9	0.3	0.3	0.6
System3																			
System4																			
System5																			
System6																			

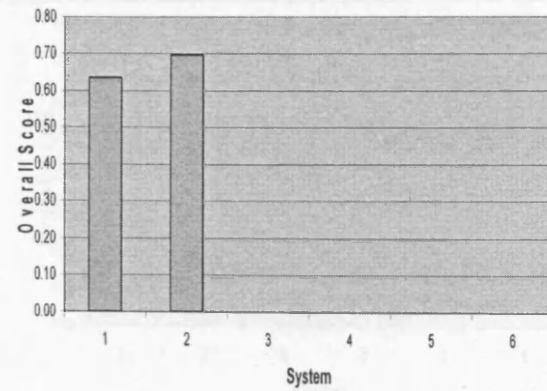
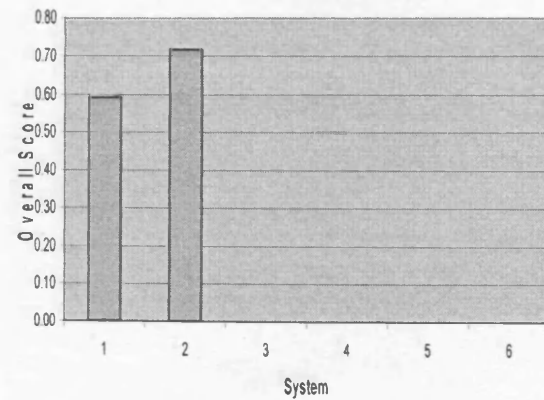


Table A10 – 5 Space Agencies' Requirements Rating

Solar Physics Workshop: Technology Evaluation - MSSL Eng Groups

MSSL Eng Groups

	Attributes																		
	Science	Publicity	Tech Transfer	Training	Kudos	Opportunities for Research	Data	Facilities to Use	Teaching	Money	RAE	Technology	Instruments	Excitement	Interest	National Pride	Direction to Their Programmes	Opportunity to Influence the Bigger Picture	Jobs
	0.2	0.5	0.7	0.6	0.6	0.1	0.1	0	0.3	0.9	0.2	0.9	0.5	0.5	0.8	0.4	0.3	0.5	0.7
System	Scores																		
System1	0.9	0.7	0.3	0.3	0.8	0.8	0.9	0.9	0.9	0.7	0.8	0.5	0.5	0.9	0.9	0.7	0.5	0.5	0.5
System2	0.8	0.7	0.7	0.7	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.3	0.9	0.9	0.9	0.3	0.3	0.8
System3								1											
System4								1											
System5								1											
System6								1											



Solar Physics Workshop: Technology Evaluation - PPARC

PPARC

Attributes																			
	Science	Publicity	Tech Transfer	Training	Kudos	Opportunities for Research	Data	Facilities to Use	Teaching	Money	RAE	Technology	Instruments	Excitement	Interest	National Pride	Direction to Their Programmes	Opportunity to Influence the Bigger Picture	Jobs
Weight	0.9	0.9	0.6	0.3	0.9	0.8	0.8	0.6	0.7	1	0.7	0.6	0.2	0.4	0.2	0.7	0.7	0.7	0.3
Scores																			
System1	0.9	0.7	0.3	0.3	0.8	0.8	0.9	0.9	0.9	0.4	0.8	0.5	0.5	0.9	0.9	0.7	0.5	0.5	0.7
System2	0.8	0.7	0.7	0.7	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.3	0.9	0.9	0.9	0.3	0.3	0.7
System3																			
System4																			
System5																			
System6																			

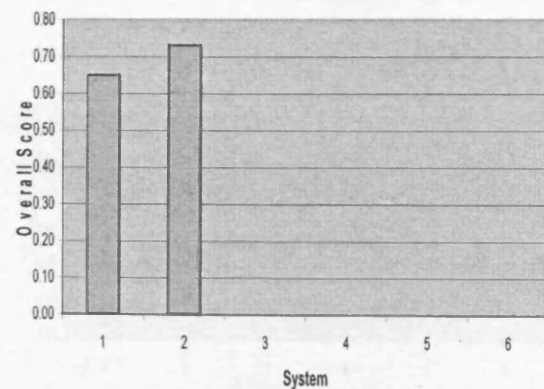


Table A10 – 7 PPARC's Requirements Rating

Solar Physics Workshop: Technology Evaluation - Space Weather Community

Attributes																			
	Science	Publicity	Tech Transfer	Training	Kudos	Opportunities for Research	Data	Facilities to Use	Teaching	Money	RAE	Technology	Instruments	Excitement	Interest	National Pride	Direction to Their Programmes	Opportunity to Influence the Bigger Picture	Jobs
Weight	0.5	0.3	0	0	0	0.3	1	0.7	0	1	0	0	0	0	0	0	0	0.3	0.2
System	Scores																		
System1	0.8	0.7	0.3	0.3	0.8	0.8	0.9	0.9	0.9	0.5	0.8	0.5	0.5	0.9	0.9	0.7	0.5	0.5	0.5
System2	0.9	0.7	0.7	0.7	0.9	0.9	0.8	0.9	0.9	0.9	0.9	0.9	0.3	0.9	0.9	0.9	0.3	0.3	0.9
System3			1	1	1				1	1	1	1	1	1	1	1	1		
System4			1	1	1				1	1	1	1	1	1	1	1	1		
System5			1	1	1				1	1	1	1	1	1	1	1	1		
System6			1	1	1				1	1	1	1	1	1	1	1	1		

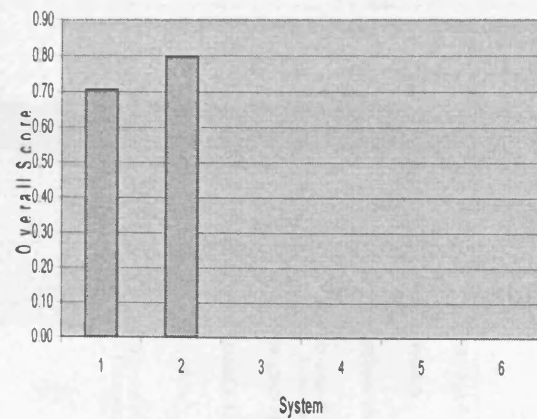


Table A10 – 8 Space Weather Community's Requirements Rating

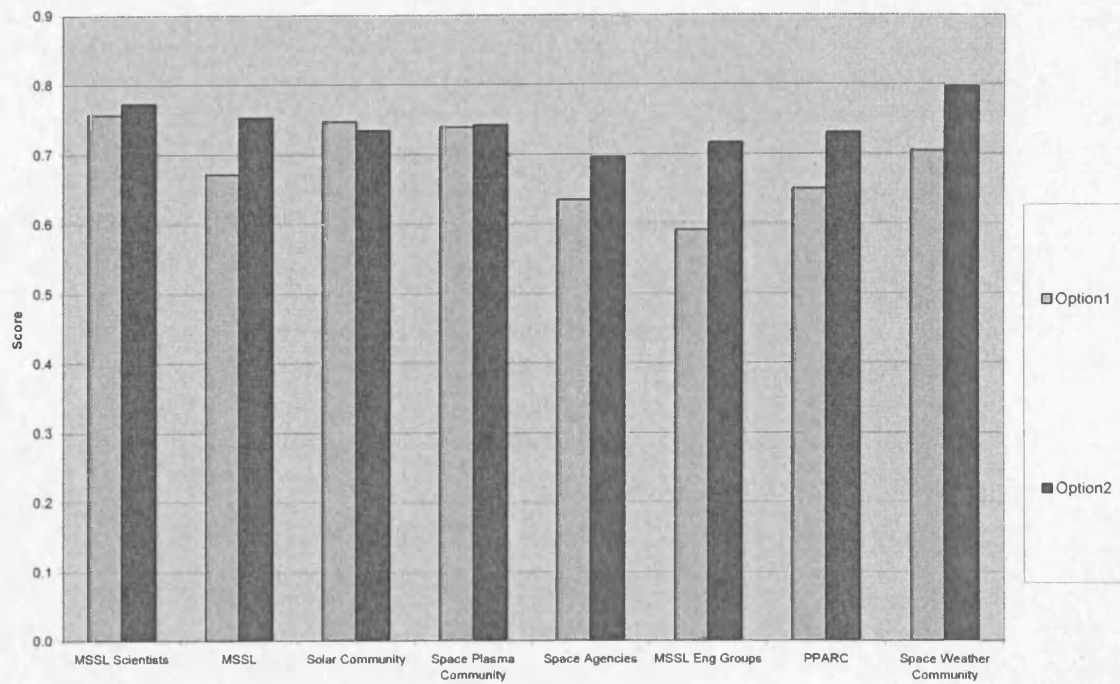


Table A10 – 9 Score By Stakeholder

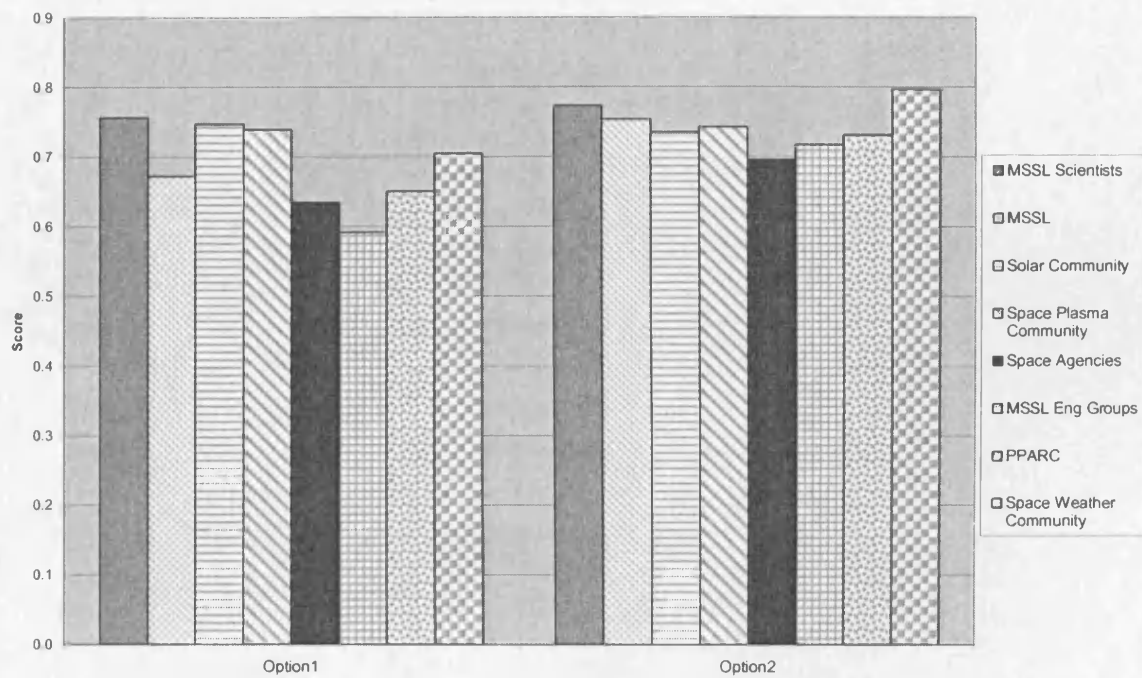


Table A10 – 10 Score By Option

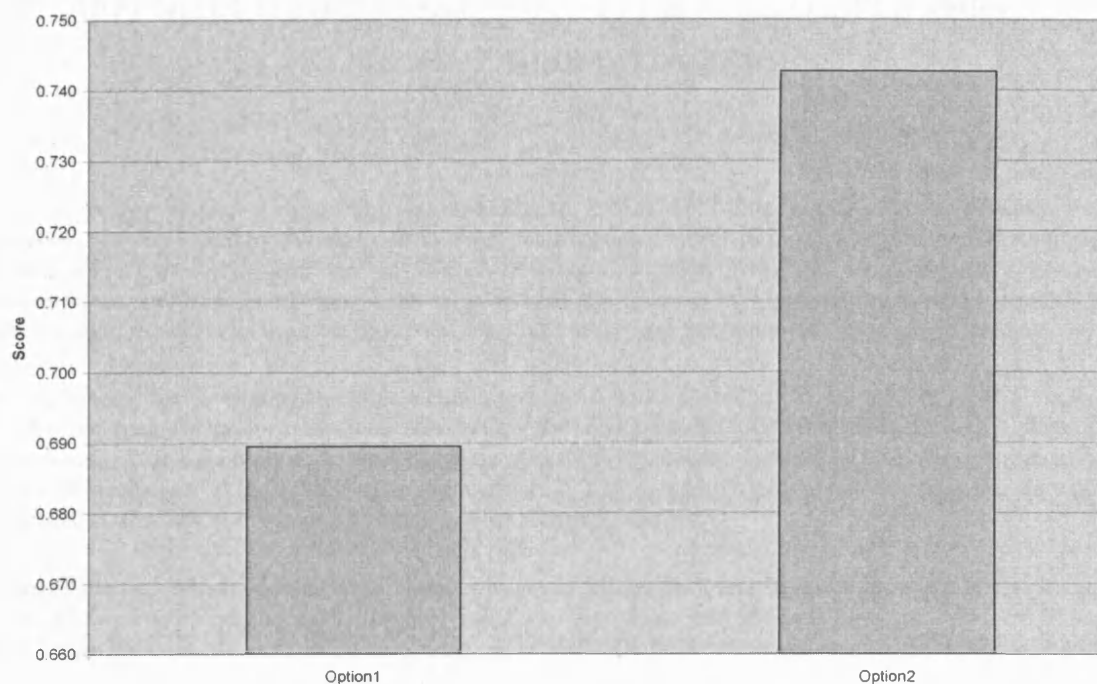


Table A10 – 11 Overall Score

Solar Physics Workshop: Technology Evaluation

Weight	Stakeholder								Overall	System Description
	0.145	0.130	0.130	0.130	0.130	0.116	0.116	0.101		
	MSSL Scientists	MSSL	Solar Community	Space Plasma Community	Space Agencies	MSSL Eng Groups	PPARC	Space Weather Community		
Option1	0.757	0.672	0.747	0.739	0.635	0.592	0.651	0.705		0.689
Option2	0.773	0.754	0.735	0.743	0.696	0.717	0.731	0.797		0.743
System3	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000
System4	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000
System5	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000
System6	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000

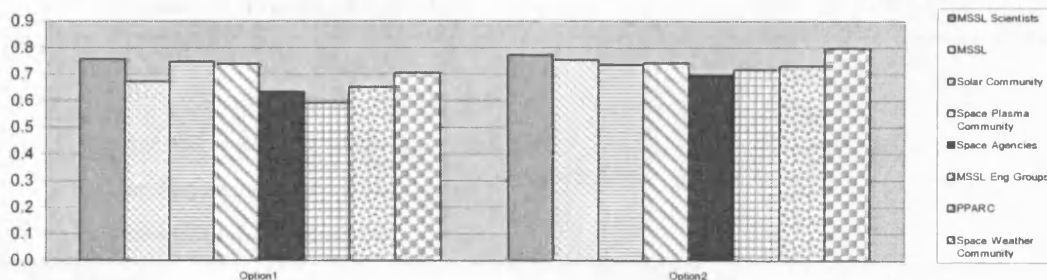
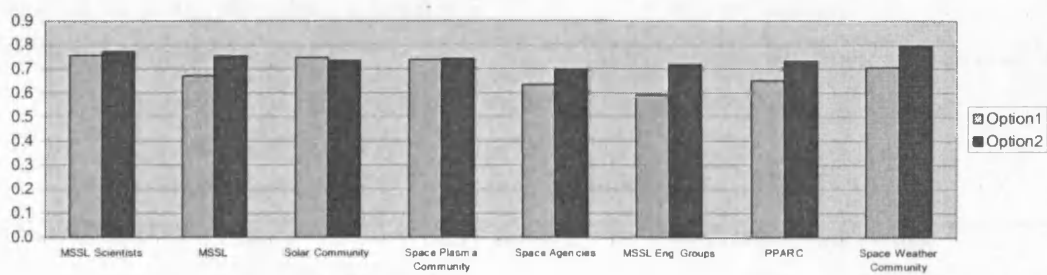


Table A10 – 12 Option Summary

APPENDIX 11 ORGANISATION 1 TECHNOLOGY PLANNING

WORKSHOP DELEGATE BRIEF

UCL's Centre for Systems Engineering was awarded an EPSRC-DTI Intersect (Intelligent Sensing) Faraday Partnership Flagship Grant to investigate technology planning and acquisition in the instrumentation supply chain. The stakeholders in this project include GlaxoSmithKline, Syngenta, NPL and Sira Ltd and a number of instrumentation suppliers. The project's aim is to address the situation in which an organisation depends upon instrumentation to deliver its business processes but does not develop instrumentation as its core business.

A generic process for developing workable technology plans is under development. In order to validate this model a number of trial Technology Planning Workshops are being carried out within the project's participating organisations. For organisation 1, two half-day workshops exploring technology for the quantification of compounds synthesised in high throughput chemistry (HTC) are planned. Ideally this technology should work for all structural classes and not require calibration against authentic samples.

The aim of the first half-day workshop (8th July) is to get to grips with the problem rather than come to a solution. The aim of the second half-day workshop (20th July) is to investigate and trade off potential solutions. Please see agenda below.

	Half-Day 1 (8 th July)		Half-Day 2 (20 th July)
13:30	Introduction <ul style="list-style-type: none"> - Objectives - TRIZ - Problem domain - Problem definition 	13:30	Review of first half-day workshop
14:00	Stakeholder analysis (including revisit of problem definition)	13:45	List of possible solutions (including costs and benefits)
15:00	Clarify trade off behind problem	14:15	Cost benefit analysis and solution evaluation
15:30	Coffee	15:15	Coffee
15:45	Explore inherent problem contradiction	15:30	Improve solutions
16:15	Current system configuration (This will involve exploring the resources in the existing quantification systems for HTC and Microfluidics)	16:00	Prioritise solutions and generate technology roadmaps
16:45	Review of current system configuration exercise and mapping of resources	17:00	Workshop review exercise
17:00	Wash up & Home Work (HW: To generate a list of potential solutions, including estimated costs and benefits, to be sent to UCL prior to the second half-day workshop)	17:15	Wash up
17:30	Depart	17:30	Depart

Douglas Cowper

University College London

APPENDIX 12 PRECISION FARMING ALLIANCE TECHNOLOGY PLANNING WORKSHOP

Organisation 2 Technology Planning Workshop : Delegate Brief

Precision Farming Alliance



Silsoe Research Institute, Wrest Park, Silsoe, Bedfordshire MK45 4HS, UK

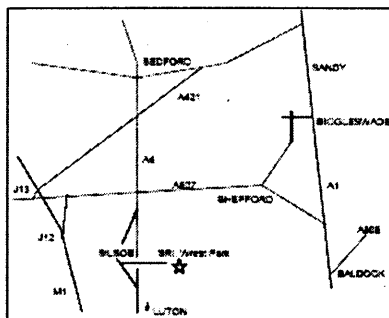
Tel: +44 (0)1525 861809 Fax: +44 (0)1525 861697 E-mail: p.f.alliance@bbsrc.ac.uk

Alliance Meeting - Thursday 30th September 2004

PFA Open Meeting at Silsoe Research Institute, Wrest Park, Silsoe, Bedfordshire.

PRECISION TECHNOLOGY PLANNING WORKSHOP

The Alliance is pleased to host an important Workshop which will be run by researchers from University College at London University. The team from UCL have been involved with several members of the Alliance in this project, and intend that the Workshop should provide a feedback from their study to date. They are working on the definition of some of the key factors which are required for the implementation and use of precision farming techniques to be effective. They have been investigating issues such as compatibility and cost-effectiveness, and the importance of the relationships between the farmer and the equipment and technology supplier.



The day is planned to be very interactive, as they believe that while they have much information from the results of their work to date to share with delegates to the Meeting, they also require validation of assumptions and guidance as to the needs of farmers and to hear some of the issues which have been found by those already supplying tools into this area.

This is an important Meeting for the Alliance and could have a significant influence on the resources which will be available to farmers tomorrow. It is hoped that we will have a good attendance of Members, their guests and others so that the maximum benefit can be obtained from this opportunity to influence the way the tools of PF are developed, made available and integrated.

Programme:

- 10.00 Arrive, Registration and Coffee.
- 10.30 Alliance AGM (Members only).
- 11.15 Background to the UCL project, results to date and objectives for the Workshop.
- 12.00 Workshop session:
 - What do farmers need from PF technologies and what do they want from the systems?
- 1.00 Lunch.
- 1.30 Workshop sessions (cont.):
 - What technology already exists and where are the gaps?
 - What compatibility standards are required?
 - What benefits should be achievable from adopting PF techniques?
- 4.00 Tea and depart.

August 2004

European Economic Interest Group (EEIG) Registered in England N°: GE95

The EEIG may only be bound by the joint action of two or more managers.



Precision Farming Workshop – Syndicate Exercise Results

Michael Emes, Doug Cowper, Alan Smith

University College London

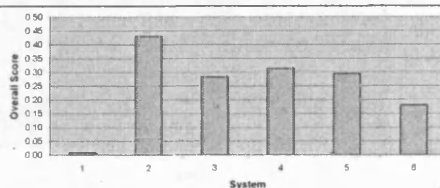
Stakeholder Groups

- There were approximately 34 people at the Precision Farming Alliance meeting on 30th Sep 04 held at Silsoe Research Institute, Wrest Park.
- For the syndicate exercises, these people were split into groups according to which 'stakeholder' they were approximately as follows:

– Farmers	4
– Equipment/Software supplier	12
– Agronomists	10
– Chemical Supplier	4
– Retailer	1
– University	3

Farmer Ratings

System	Attributes									Weighted
	Cost	Reliability	Cost Effective	Compatibility	Ease of Use	Flexibility	Accountability	Optimising Inputs/Yields	Timeliness	
Weight	1.5	4	5	2	3	2	1.5	1	1	
System	Scores									
System1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
System2	0.3	0.7	0.5	0.01	0.9	0.7	0.7	0.9	0.9	0.43
System3	0.2	0.1	0.5	0.1	0.4	0.4	0.6	0.6	0.3	0.28
System4	0.3	0.3	0.2	0.1	0.4	0.5	0.7	0.5	0.6	0.31
System5	0.2	0.4	0.2	0.1	0.3	0.3	0.6	0.6	0.6	0.29
System6	0.1	0.1	0.2	0.1	0.2	0.1	0.6	0.8	0.9	0.18



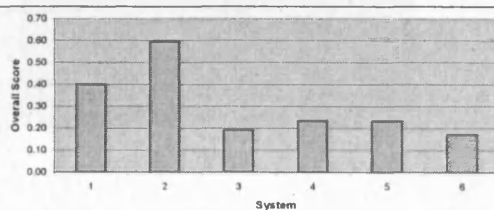
- Farmers couldn't see the point in System1 and therefore gave it very low scores across the board
- Farmers were sceptical about the ability of Systems 3-6 to work in practice, given difficulties they had had with compatibility, reliability etc. of simpler systems

Precision Farming Workshop Results, 30th Sep 04

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Equipment/Software Supplier

System	Attributes									Weighted
	Help Customer	Meet Legislation	High Volume	Compatibility HW	Compatibility SW	Simple to Use	Integration	Data Standards		
Weight	3	2	1	4	4	3	2	3		
System	Scores									
System1	1	0.1	0.1	1	1	0.05	1	1	0.1	0.40
System2	0.8	0.3	0.1	0.9	1	1	0.9	1	0.1	0.60
System3	0.4	0.6	0.7	0.2	0.1	0.4	0.1	0.1	0.1	0.19
System4	0.6	0.4	0.7	0.3	0.2	0.4	0.1	0.1	0.1	0.24
System5	0.6	0.4	0.7	0.3	0.2	0.4	0.1	0.1	0.1	0.24
System6	0.2	0.7	0.9	0.1	0.1	0.4	0.2	0.1	0.1	0.17



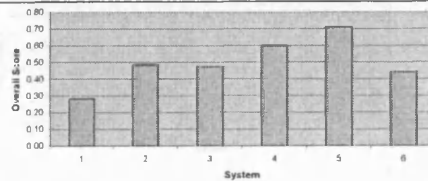
- It is interesting to note that equipment suppliers felt that much of the specialist equipment was difficult for farmers to use and that software and hardware standards might be a problem with these

Precision Farming Workshop Results, 30th Sep 04

6

Agronomist Ratings

Attributes												
Common												
	High Take Up	Ease of Use	Reliable	Cost Effective	Terminology + Standards	Compatibility of Systems	Tailored Output of Data	Availability of Good Training	Record Inputs + Outputs	Warning of Errors	Confidence in Data	
Weight	1	4	4	4	1	3	2	1	4	2	2	9
System	Scores											Weighted
System1	0.5	0.5	0.5	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.25
System2	0.5	0.7	0.5	0.5	0.2	0.2	0.2	0.4	0.2	0.5	0.5	0.45
System3	0.3	0.2	0.2	0.5	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.47
System4	0.5	0.3	0.4	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.50
System5	0.5	0.5	0.7	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.71
System6	0.1	0.1	0.1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.44



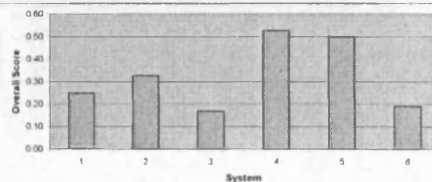
- Agronomists were sceptical that System 5 with variable N could work in practice, but rated a System 5 with variable P and K very highly
- Chemical suppliers argued that System 5 with variable N could work

Precision Farming Workshop Results, 30th Sep 04

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Chemical Supplier Ratings

Attributes												
Common												
	High Take Up	Ease of Use	Reliable	Cost Effective	Terminology + Standards	Compatibility of Systems	Tailored Output of Data	Availability of Good Training	Record Inputs + Outputs	Warning of Errors	Confidence in Data	
Weight	3	4	4	4	2	2	3	3	1	2	3	
System	Scores											Weighted
System1	0.05	1	0.9	0.25	1	1	0.25	0.2	0.05	0.05	1	0.35
System2	0.3	0.5	0.7	0.3	0.5	0.7	0.2	0.3	0.05	0.05	0.3	0.33
System3	0.2	0.2	0.1	0.1	0.5	0.4	0.5	0.1	0.7	0.05	0.1	0.17
System4	0.5	0.4	0.7	0.5	0.5	0.4	0.7	0.5	0.5	0.05	0.5	0.53
System5	0.5	0.4	0.5	0.5	0.4	0.3	0.7	0.5	0.5	0.05	0.5	0.50
System6	0.1	0.1	0.2	0.2	0.1	0.2	0.5	0.2	0.5	0.05	0.5	0.19

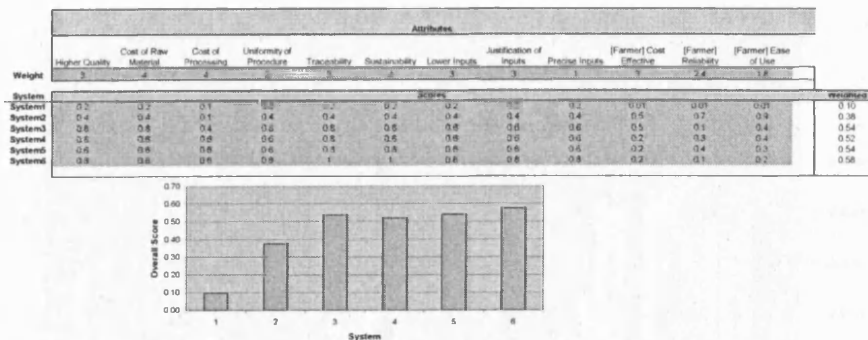


- Agronomists were sceptical that System 5 with variable N could work in practice, but rated a System 5 with variable P and K very highly
- Chemical suppliers argued that System 5 with variable N could work

Precision Farming Workshop Results, 30th Sep 04

8

Retailer Ratings

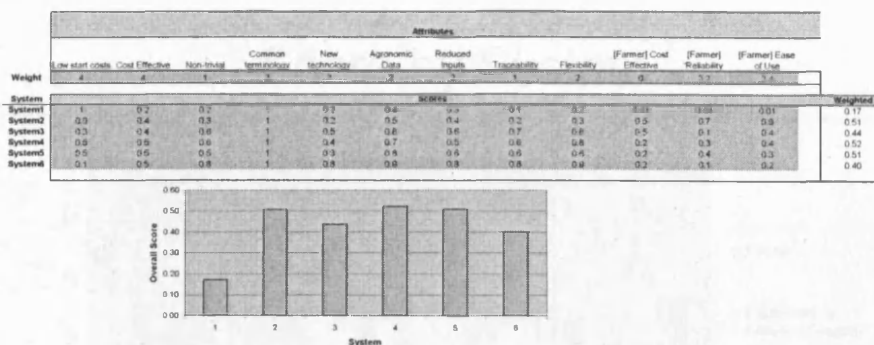


- * Retailers favoured sophisticated systems that could offer traceability of inputs, and were less concerned with ease of operating and compatibility issues

Precision Farming Workshop Results, 30th Sep 04

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University Ratings (UCL)

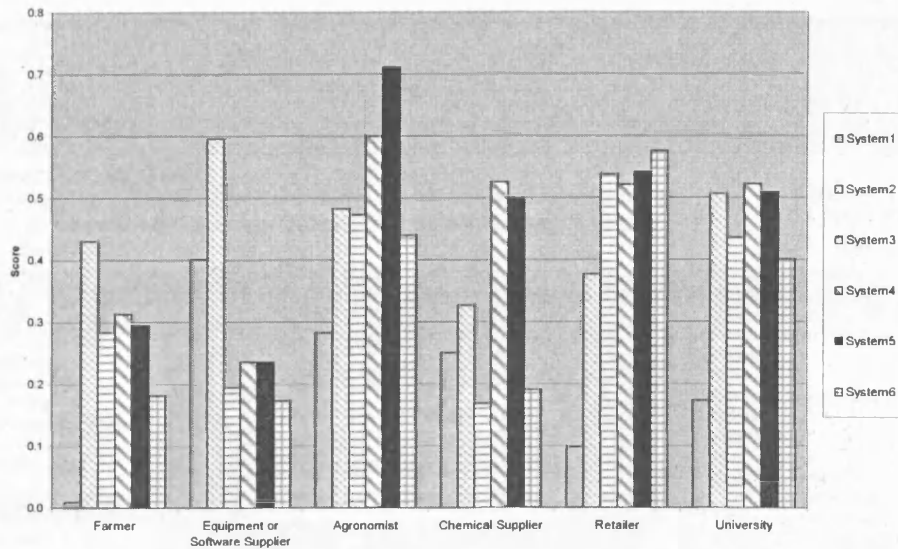


- * Note that universities identified 'Farmer' as an important attribute (and gave it a weighting of 4). This means that universities are interested in those attributes identified by farmers as important, as this drives uptake of precision farming. We have taken the 3 most important attributes to farmers and added these to the universities attribute list, together with the farmers' scores for the systems. We gave the farmers' most important attribute (cost effective) a weighting of 4, and reduced the others in proportion to the farmers' weightings. Reliability therefore became $4 \times 4/5 = 3.2$
- * Since universities identify 'Cost Effective' as important because it determines uptake, this is effectively the same as the [Farmer] Cost Effective attribute. In this case, we choose the attribute with the higher weighting and set the other weighting to zero.
- * If the weightings are the same (as in this case), we give preference to the stakeholder's own rating. If the attributes are duplicated but for different reasons, then both the ratings are counted as normal.

Precision Farming Workshop Results, 30th Sep 04

10

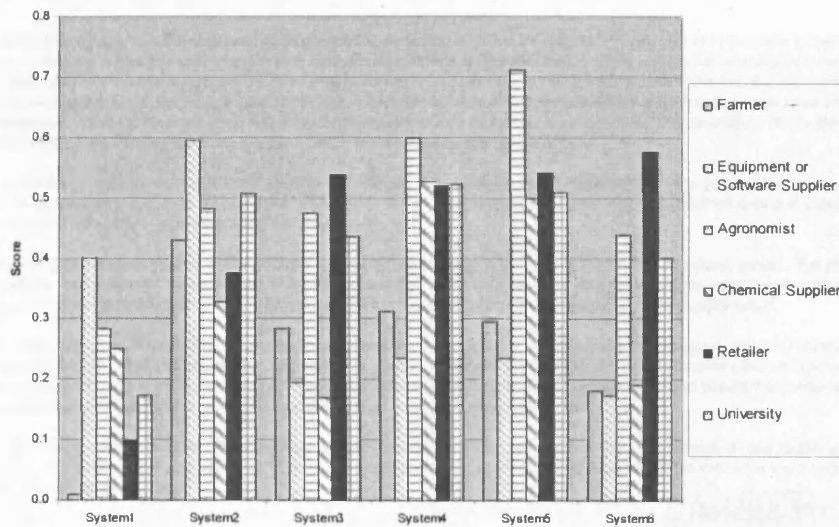
Score by Stakeholder



Precision Farming Workshop Results, 30th Sep 04

11

Score by System



Precision Farming Workshop Results, 30th Sep 04

12

Figure A12 – 1 Precision farming Alliance Technology Planning Workshop Syndicate Exercise Results Slides

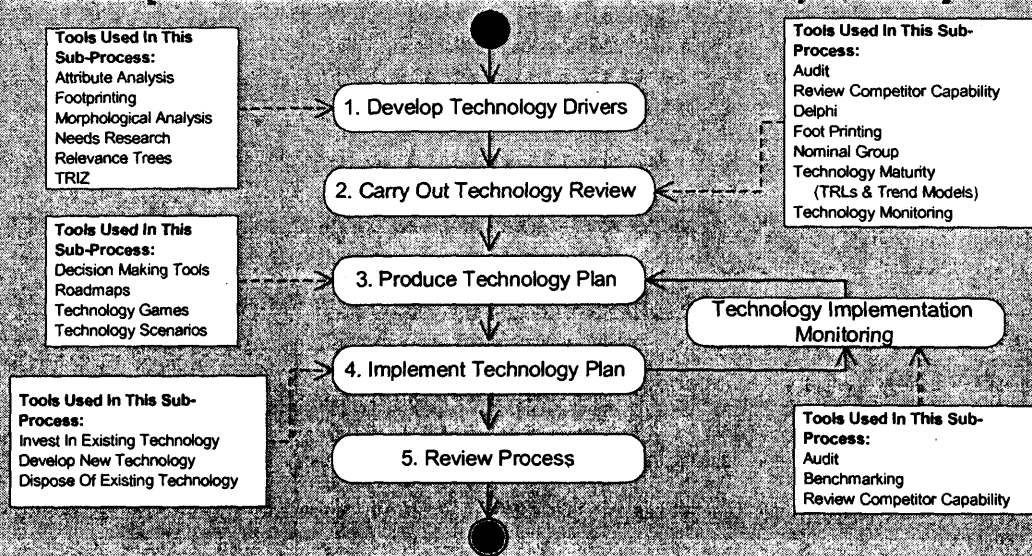
Technology Planning & Management Lifecycle

Purpose/Aim of Tool:

To make technology planning more accessible to organisations, reduce the risk in technology development and to ensure poor technology management is not a barrier to innovation.

When to use:
Over complete lifecycle

Process: [uses both internal and external resources and processes]



Notes:

1. Develop the technology drivers from the business and marketplace needs (the business case for technology needs to be made to higher management and the mismatch between technology and product lifecycles needs to be addressed). The technology drivers should include: "what information do I need, what are the inputs and outputs, what help is available and what are the costs and benefits?" Market and competitor assessment tools are used to provide inputs to the technology plan. These inputs can also come from feedback from the organisation's sales force and maintenance engineers. Customers may also drive and fund technology development within the supply chain and competition drives the time to market. Therefore, the technology plans of customers and suppliers needs to address this interdependency.
2. Carry out a technology review to understand where existing technologies are, where the technologies of interest are going and how good the organisation and its competitors are at these technologies. The review should also identify threats from substitute technologies and should address the new technologies that will affect the organisation's existing business.
3. Use the information gathered during the technology review to develop a technology plan that addresses the technology drivers. The planning process should include cost/benefit and make/buy decisions and will usually have a finite duration. Due to the interdependence of customer and supplier technology plans, the technology plan should be passed down to suppliers once developed and during implementation.
4. Implement the technology plan; this includes determining how technology is brought into the business and developed, how it is maintained and how it is to be disposed of. If the plan needs to address the substitution of a technology, then the introduction of the substituting technology needs to be co-ordinated with the disposal of old technology. During the process monitoring and auditing of the implementation to ensure it is conforming to the plan. Any deviations will result in either an amendment to the implementation or an amendment to the plan.
5. At the end of the planning period the implementation of the whole technology planning process is reviewed to provide an opportunity for process improvement. It should be stressed that any obvious problems with the implementation of this lifecycle should be addressed at the time of discovery and not held back until this review process.

Additional Notes:

- Establish a time frame for the planning lifecycle. This may be different to the time frame for the development of the technology.
- Need to allocate a budget and resource for this activity.
- Requires management commitment.

Roles & Responsibilities

Process Owner:
Senior Management

Participants:
Individuals from the business and from external organisations

Develop Technology Drivers

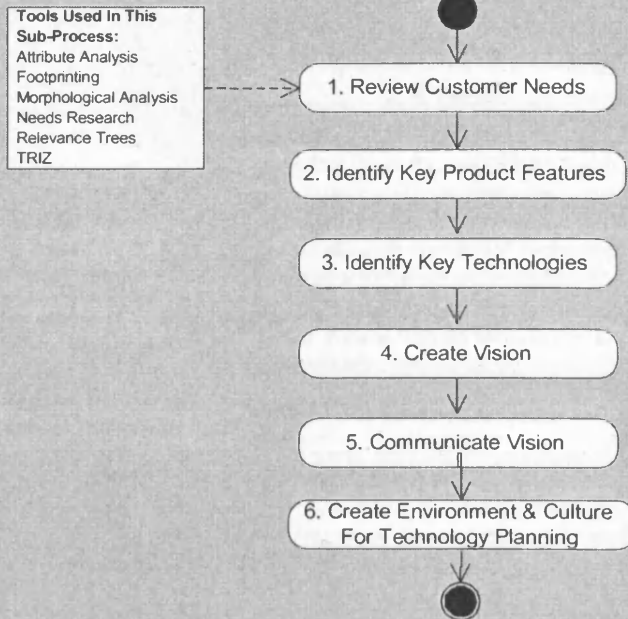
Purpose/Aim of Tool:

To identify the market and business technology requirements.

When to use:

First lifecycle process

Process: [uses both internal and external resources and processes]



Notes:

1. The customer needs review forms the basis of the future system capability.
2. This activity translates the future system capability into key product features (technology capability).
3. This activity identifies key technology solutions that will deliver the technology capability.

Additional Notes:

- The Business Objectives should include funding streams, budgetary constraints and cycles.
- Includes existing market new technology and new market existing technology.
- Customers & users may suggest new ideas.
- Marketing should communicate customer capability requirements and not technology solutions.
- Market Research can over estimate demand.

Roles & Responsibilities

Process Owner:
Senior Management.

Participants:
Individuals from the business and from external organisations

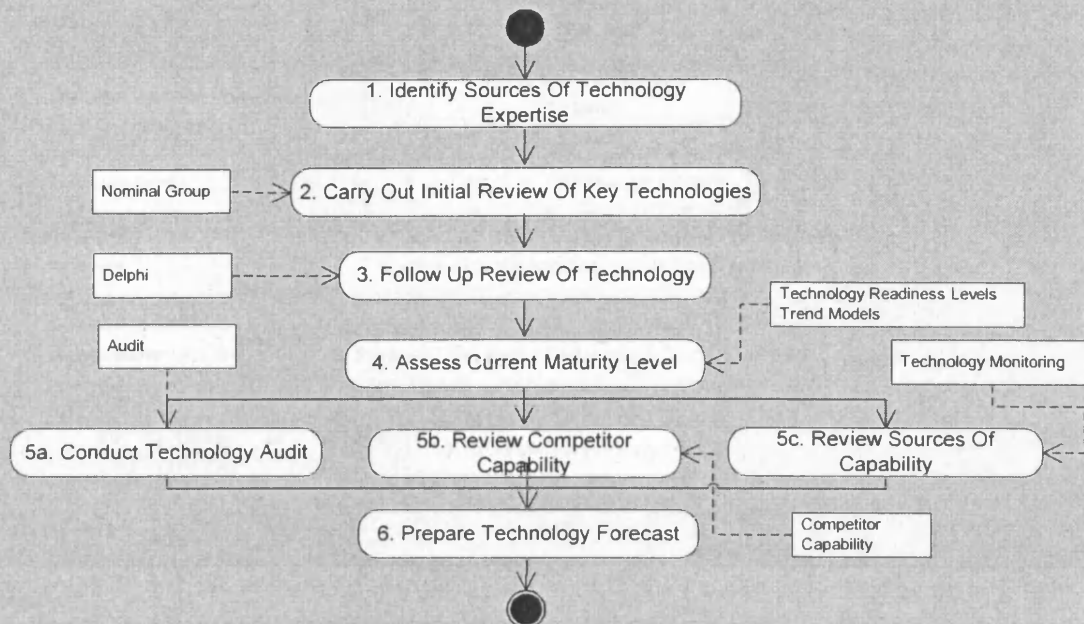
Technology Review

Purpose/Aim of Tool:

To establish the technology landscape - what level of maturity is the technology, how much more performance increase can be achieved, what technologies are potential substitutes, what capability does the competition have, who can I turn to for help?

When to use:
Second lifecycle process

Process: [uses both internal and external resources and processes]



Notes:

2 & 3. These activities identify: the rate of change, natural limit, substitute technologies, level of risk and research activity for each technology.

5a. To conduct this activity you need to identify which organisations are the technological leader.

6. The technology forecast needs to identify step changes in the technology which can then be used to assess how this ripples through the supply chain.

Roles & Responsibilities

Process Owner:

Technology Manager

Participants:

Individuals from the business and from external organisations

Additional Notes:

New ideas can come from suppliers.

Some suppliers are earlier adopters of technology than others.

There may be some internal co-ordination of market intelligence within supplier.

Intermediaries may spin off technology suppliers.

New ideas can come from support groups.

Do you have the knowledge or skills to do this?

Who can you turn to for help?

If you get stuck can you identify who can help?

Is there anyone who can help you find the right people?

Keeping up to date with technology is difficult if you are not a specialist.

Produce Technology Plan

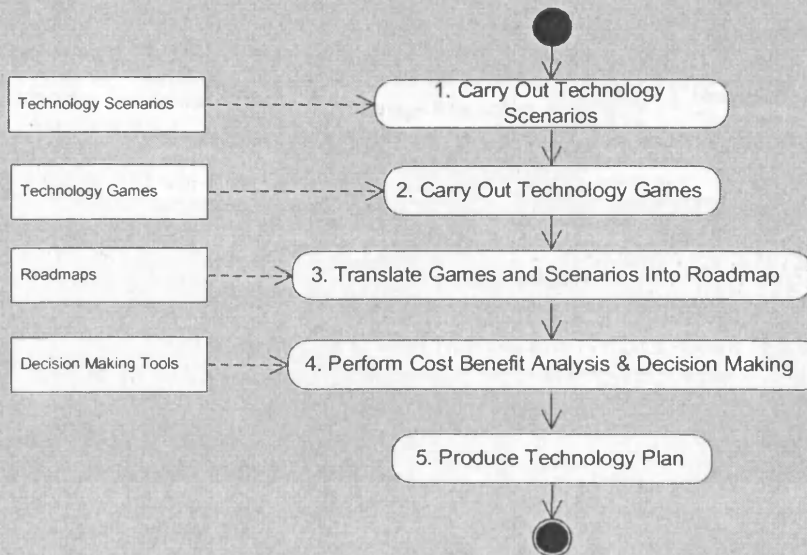
Purpose/Aim of Tool:

To explore the technology landscape for various scenarios and to decide what course of action the technology plan should take.

When to use:

Third lifecycle process

Process: [uses internal resources]



Notes:

1. Explore the technology landscape using either/or technology games and scenarios.
2. Translate the games and or scenarios into technology roadmaps.
3. Explore all the options using a cost benefit analysis model to decide upon most desirable approach.
4. Turn the desired approach into a plan of activities, investment profile, milestones with expected maturity levels.
5. The plan will typically be a project plan. This plan needs to link to customer and supplier plans.

Additional Notes:

Road mapping can get complex very quickly. The scenario & game theory activities should reduce the complexity of the roadmap by focusing on particular desirable outcomes.

Technology sourcing involves a compromise between keeping options open and backing a particular technology and involves a formal assessment of the attractiveness of technology.

Decision should include investment vs. payback in future sales.

Collaborations and teaming can provide critical mass for technology development.

Step changes in the technology need to be assessed to indicate the impact on the supply chain.

Technology breakthrough may require openness with supplier.

Technology Planning can be constrained by internal bidding and competition over funds.

Roles & Responsibilities

Process Owner:

Senior Management.

Participants:

May include some individuals from the business

Implement Technology Plan

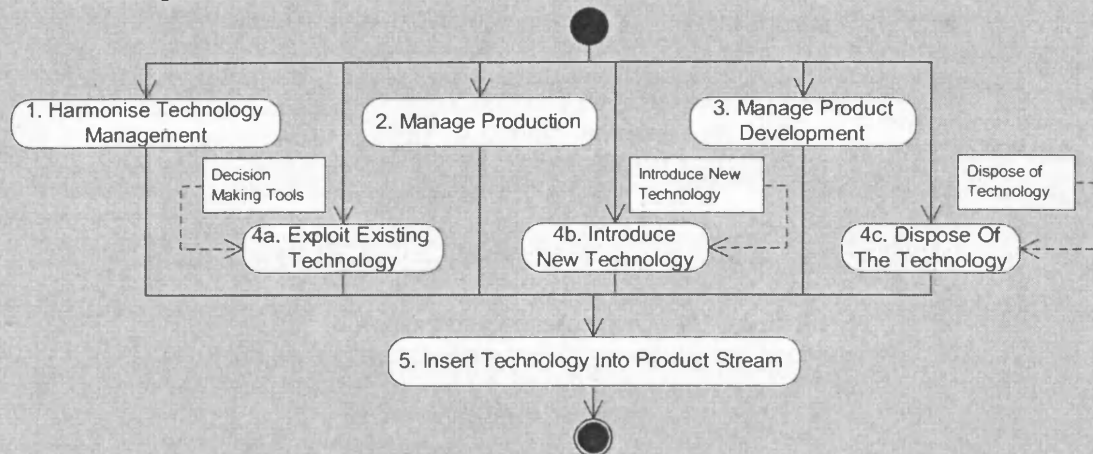
Purpose/Aim of Tool:

To implement the technology plan.

When to use:

Fourth lifecycle process

Process: [uses both internal and external resources and processes]



Notes:

1 - 3. Running in parallel is a harmonise technology management activity to ensure the development of technology is linked to the manufacturing and engineering processes.

4. For the implementation of each technology there are 3 options:

- 4a. Invest in existing technology.
- 4b. Introduce a new technology.
- 4c. Dispose of the technology.

The last two (4a & c) require some co-ordination to prevent any gaps occurring between existing and replacement technologies.

Additional Notes:

Flowing between the harmonise technology management and the technology implementation, manage production and engineering activities are control of the processes and information (not shown).

Roles & Responsibilities

Process Owner:

Senior & Functional Level Management.

Participants:

Individuals from the business and from external organisations

Technology Implementation Monitoring

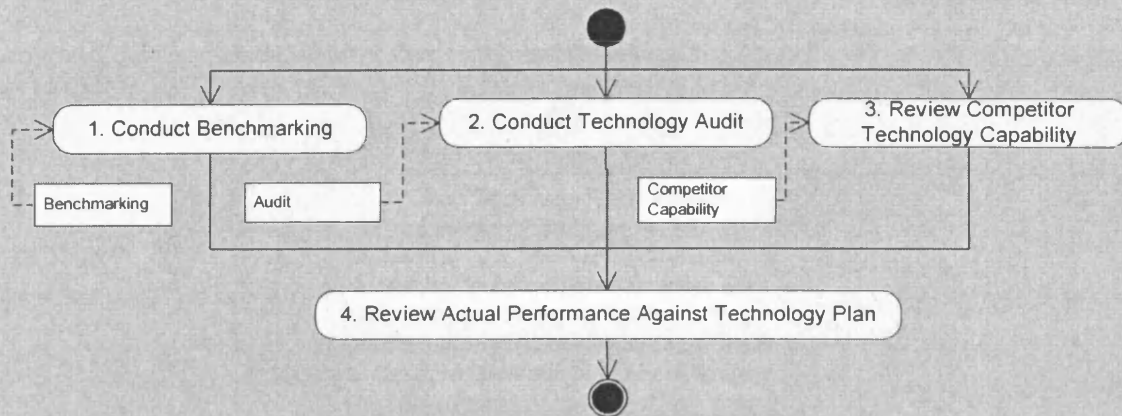
Purpose/Aim of Tool:

To monitor and control the implementation of the technology plan.

When to use:

During the implementation of the technology plan

Process: [uses both internal and external resources and processes]



Notes:

The monitoring of the implementation of the technology consists of 3 techniques:

1. Technology Auditing.
2. Technology Benchmarking.
3. Competitor Capability Review.

The information gathered from these three techniques can be used to review actual performance against the planned performance. Any differences can result in either: the implementation being left alone, amend the implementation, or amendments to the plan.

Additional Notes:

Roles & Responsibilities

Process Owner:

Senior & Functional Level Management.

Participants:

Individuals from the business and from external organisations

Attribute Analysis

Purpose/Aim of Tool:

The aim of this tool is to identify the attributes of existing technology in new applications and new technology in existing applications.

When to use:

When reviewing customer needs as part of the development of technology drivers

Process: [uses both internal and external resources]



Notes:

2. Analyse the technology for alternative uses (new markets, products etc.):
How can it be put to other uses?; Adapted?; Modified?; Reduced?; Substituted?; Rearranged?; Reversed?; Combined?
6. Analyse the technology for use in the organisation's products/services:
How can it be put to other uses?; Adapted?; Modified?; Reduced?; Substituted?; Rearranged?; Reversed?; Combined?

Additional Notes:

Parts of this tool can be used in conjunction with other tools. For example, the first part of this process can be used in conjunction with needs research as part of the review of future customer needs.

Roles & Responsibilities

Process Owner:

Senior Management

Participants:

Individuals from the business (mainly marketing & product development)

Technology Footprinting

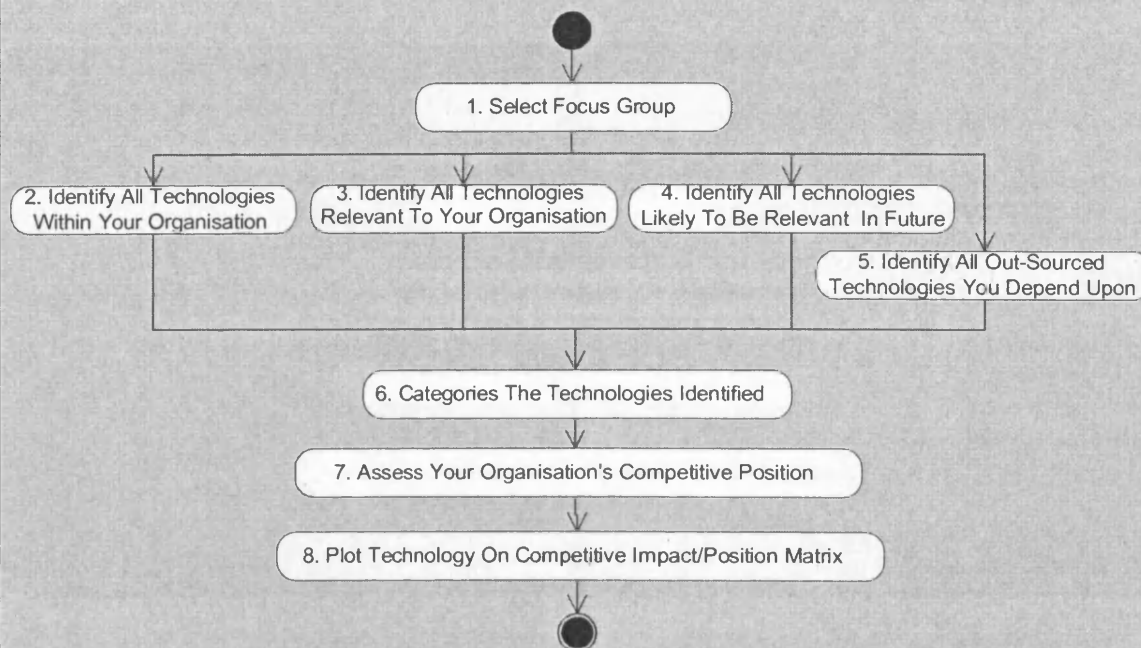
Purpose/Aim of Tool:

The aim of this tool is to provide a classification of competitive impact and position for technologies of interest to the organisation.

When to use:

Part of identifying the key technologies during the development of the technology drivers and also used for the technology review

Process: [uses both internal and external resources]



Additional Notes:

There is an assumption that the four activities in the process above can be conducted in parallel or in series.

Categorise the technologies identified in terms of:

Base technology is common to all in the industry and therefore has no impact on competitive advantage.

Key Technology is unique to an organisation and has a high impact on competitive advantage.

Pacing Technology is fairly new, but is likely to have a high impact on competitive advantage.

Emerging Technology is in its infancy and has a possibility of having a high impact on competitive advantage. However, due to its infancy, it is high risk.

Assess the organisation's competitive position for each technology in terms of:

Competitive Position:

Clear Leader The organisation sets the pace in this technology.

Strong The organisation is fully under control of this technology and is able to move in new directions.

Average The organisation is able to sustain this technology and has niche leadership.

Tenable The organisation is able to survive but is continually playing catch-up.

Weak The organisation is clearly behind the competitors and spends its time in a short-term fire-fighting role.

Roles & Responsibilities

Process Owner:

Technology Manager

Participants:

Individuals from the business and from external organisations

Morphological Analysis

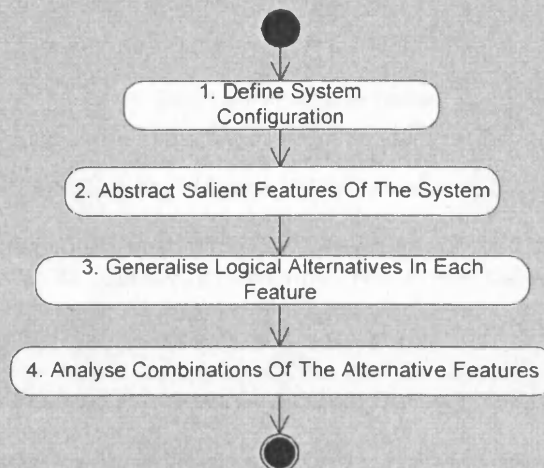
Purpose/Aim of Tool:

The aim of this tool is to identify the key product features that will satisfy future customer/market needs. The process' aim is to define the technology capability required to deliver the product or service that meets the customers/market need.

When to use:

When reviewing key product features as part of the development of technology drivers

Process: [uses both internal and external resources]



Notes:

1. Define the configuration of the system (this step uses the output from the relevance tree tool).
2. Abstract the salient features of the technical structure - what does the system need to be capable of?
3. Generalise logical alternatives for each of the salient features identified.
4. Analyse the combinations of the alternative features (this analysis needs to include a link to value and benefits that will be used during the decision making process to select the best option).

Additional Notes:

Parts of this tool can be used in conjunction with other tools. For example, the first part of this process requires the output from a relevance tree exercise to define system configurations.

Roles & Responsibilities

Process Owner:

Senior Management

Participants:

Individuals from the business (mainly marketing & product development)

Needs Research

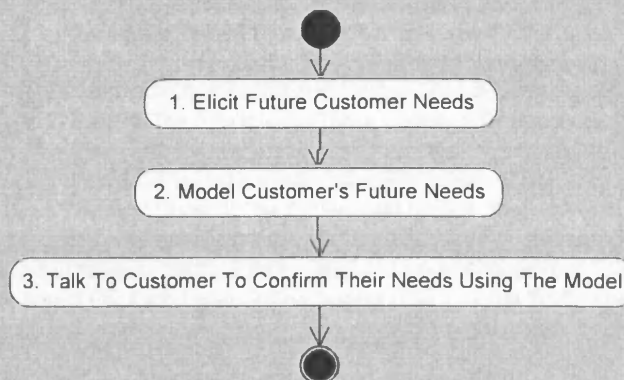
Purpose/Aim of Tool:

The aim of this tool is to identify the future needs of the customer/market place that will drive the need for new technology.

When to use:

When reviewing customer needs as part of the development of technology drivers

Process: [uses both internal and external resources]



Notes:

1. Elicit future customer needs. This can be through market survey's, phantom shopping, customer interviews, etc. The technique used in systems engineering for this is requirements engineering.
2. The future needs identified need to be understood. This can be achieved through modelling the needs.
3. Any models generated should be demonstrated to the customer/market place to verify that they are correct, validate the customer's requirement or to explore options. Once both customer and supplier are satisfied that the right need has been captured this can then be used as a driver for the technology planning and management process.

Additional Notes:

Another useful method of capturing needs is to carry out a stakeholder analysis preferably with all the stakeholders.

Useful reference:

Macaulay L A, (1996) Requirements Engineering, London, Springer - Verlag Ltd.

Roles & Responsibilities

Process Owner:

Senior Management

Participants:

Individuals from the business (mainly marketing & product development)

Relevance Tree

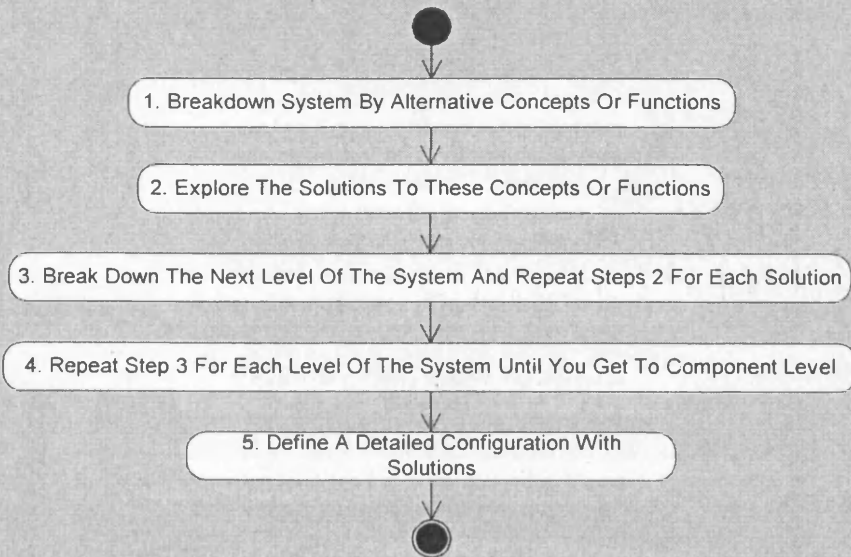
Purpose/Aim of Tool:

The aim of this tool is to explore the structural relationships of a product/component/system in a systematic way.

When to use:

To define the configuration of a system for a morphological analysis as part of the development of technology drivers

Process: [uses internal resources]



Notes:

4. Component level is the level below which you are not interested exploring further. This level will depend upon your organisation's business, product, etc.

Additional Notes:

Parts of this tool can be used in conjunction with other tools. For example, the output of this tool feeds into the morphological analysis tool to define system configurations.

Roles & Responsibilities

Process Owner:

Senior Management

Participants:

Individuals from the business (mainly marketing & product development)

TRIZ

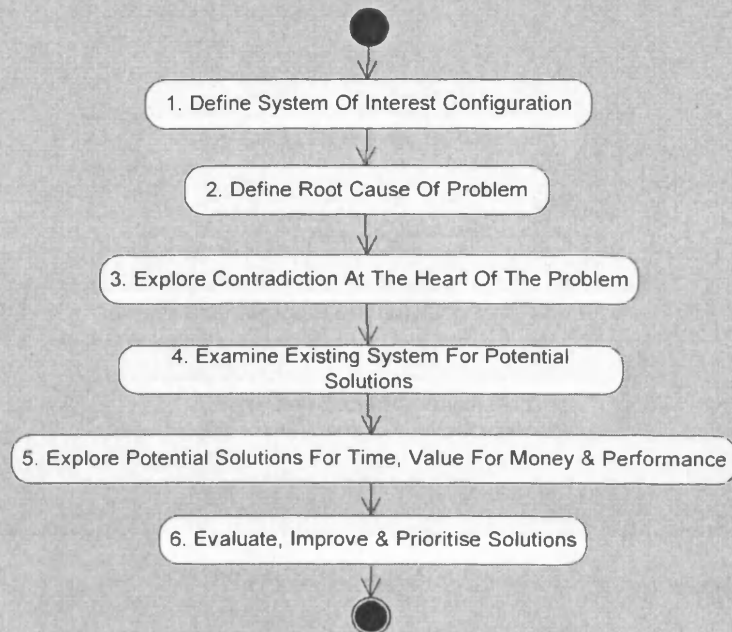
Purpose/Aim of Tool:

The TRIZ process for inventive problem solving uses a systems approach to explore contradictions within a system which prevent it from being "ideal". It also explores the resources within the system and uses 40 principles to try and resolve the contradiction.

When to use:

When identifying key technologies

Process: [uses mainly internal resources]



Additional Notes:

Useful Reference::

Simplified TRIZ - New Problem-Solving Applications For Engineers
And Manufacturing Professionals
by Kalevi Rantanen & Ellen Domb
Published by St. Lucie Press
ISBN 1-57444-323-2

Roles & Responsibilities

Process Owner:

Workshop facilitator

Participants:

Individuals from the
business and possibly some from
external organisations

Technology Audit

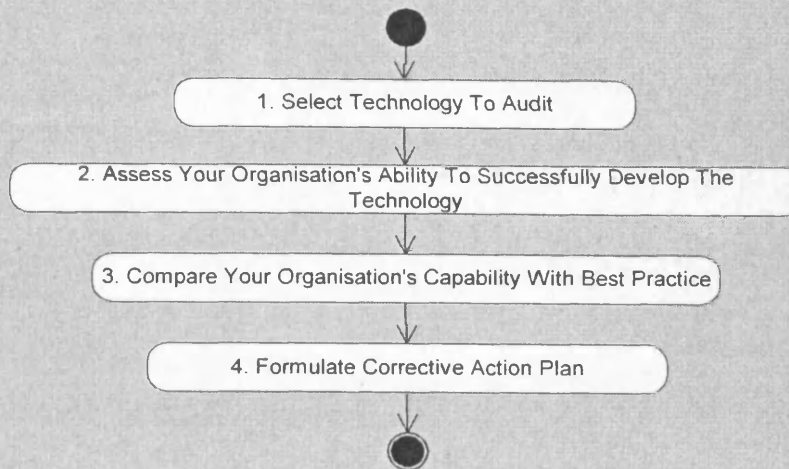
Purpose/Aim of Tool:

A technology audit's aim is to explore an organisation's ability to successfully develop and introduce new technology into the organisation. These audits may also reveal the requirement for additional forecasting and capability studies, for example benchmarking.

When to use:

During the technology review and the implementation monitoring

Process: [uses mainly internal resources]



Additional Notes:

The audit should aim to answer:

- What technologies does the company possess?
- Where did these technologies come from?
- What is the range of our technologies?
- What categories do our technologies fit into?
- What is our standing in our technologies?
- What is the life-cycle position of our technologies?
- What is our performance in acquiring technologies?
- What is our performance in exploiting technologies?
- What is our performance in managing technology?

The last part of the process is aimed at providing corrective action.

Roles & Responsibilities

Process Owner:

Technology Auditor

Participants:

Individuals from the business and from external organisations

Competitor Technology Capability

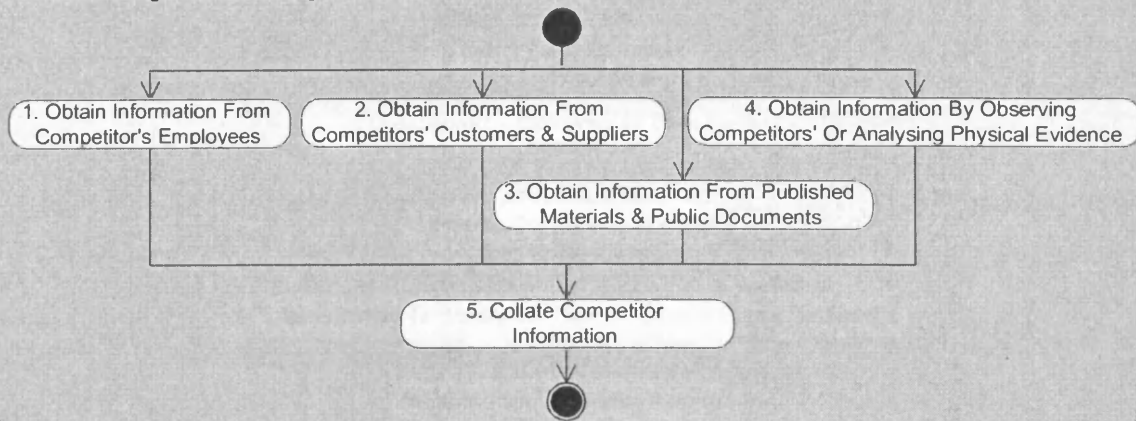
Purpose/Aim of Tool:

To review the technology capability of an organisation's competitors. Understanding what technologies an organisation's competitors are investing in and how good they are at those technologies is required as part of the technology review.

When to use:

During the technology review and the implementation monitoring

Process: [uses mainly internal resources]



Notes:

The following activities can be carried out in any order or in parallel:

1. Obtain Information From Competitors' Employees. (Conversations at trade shows, conferences etc. can provide competition information, or hire key staff from competitors.)
2. Obtain Information From Competitors' Customers & Suppliers. (Examples of this already exist in the supply chains investigated.)
3. Obtain Information From Published Materials & Public Documents. (For example, the types of people sought in help-wanted ads can indicate something about a competitor's technological thrusts. (Steven 1984, pp29-33.)).
4. Obtain Information By Observing Competitors' Or Analysing Physical Evidence. (Buying competitor's products and taking them apart. Also buying competitor's rubbish and investigating what is being thrown away!!!)
5. Collate the information collected to build a picture of the competitor's technology capability.

Additional Notes:

Useful Reference:

Steven Flax, "How to snoop on your competitors", Fortune, May 1984, pp29-33.

Roles & Responsibilities

Process Owner:

Senior Management

Participants:

Individuals from the business and from external organisations

Delphi

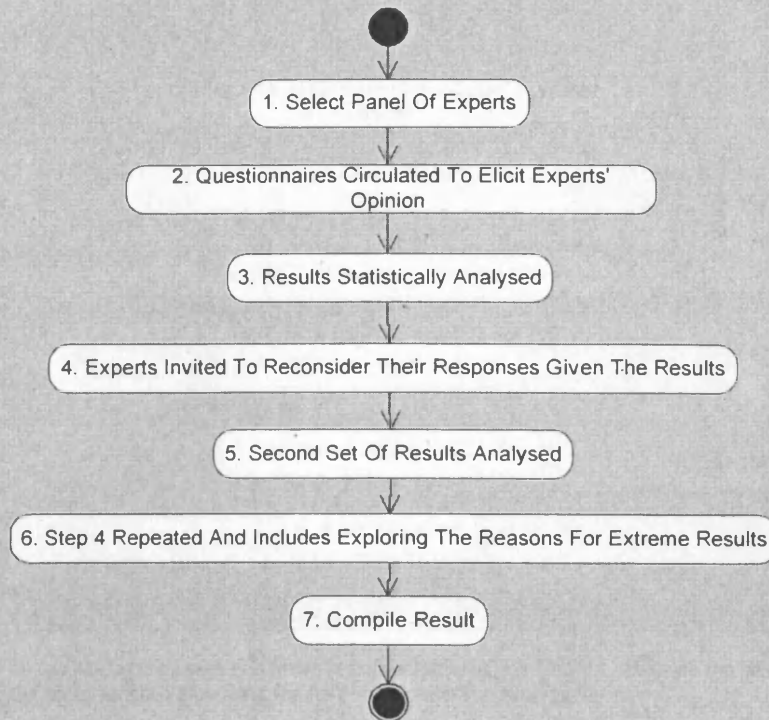
Purpose/Aim of Tool:

The aim of the delphi technique is to gain an insight into technology trends by using a panel of experts to provide an important view of technological change and direction of progress. The technique also addresses some of the drawbacks of simply convening a committee of experts in a single room.

When to use:

During the technology review phase of the lifecycle

Process: [uses both internal and mainly external resources]



Additional Notes:

Roles & Responsibilities

Process Owner:

Technology Manager

Participants:

Individuals from the business and from external organisations

Nominal Group

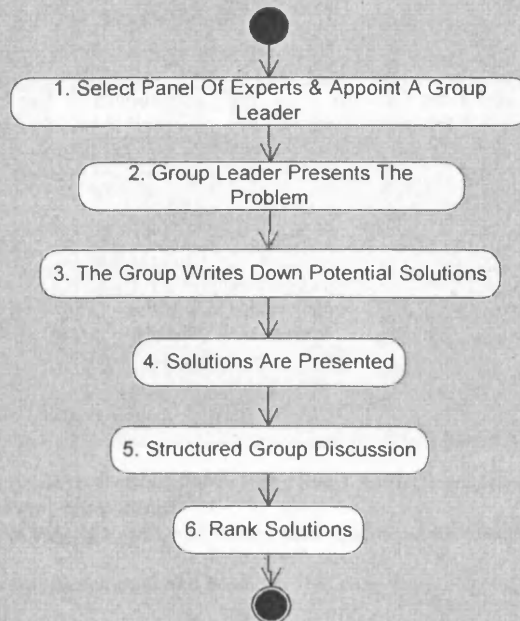
Purpose/Aim of Tool:

The aim of the nominal group technique is to gain an insight into technology trends by using a panel of experts to provide an important view of technological change and direction of progress. The technique also addresses some of the drawbacks of simply convening a committee of experts in a single room.

When to use:

During the technology review phase of the lifecycle

Process: [uses both internal and mainly external resources]



Notes:

2. The problem to be tackled by the panel of experts is presented briefly (with little detail) by the group leader. This is to avoid the group leader influencing the responses from the experts.
3. The panel then write down potential solutions without any consultation or collaboration between.
4. The solutions are presented by going round the table - one per person per round. During these presentations no discussions by the group is allowed. This requires good control by the group leader.
5. Once all the ideas have been presented a very structured group discussion is orchestrated, allowing each individual equal time.
6. Finally the solutions presented are rated using a ranking procedure, where each of the group members votes confidentially, evaluates the ideas. The results are pooled and the ranking by the group forms the decision on the relative merits of each idea.

Additional Notes:

Roles & Responsibilities

Process Owner:

Technology Manager

Participants:

Individuals from the business and from external organisations

Technology Maturity Assessment

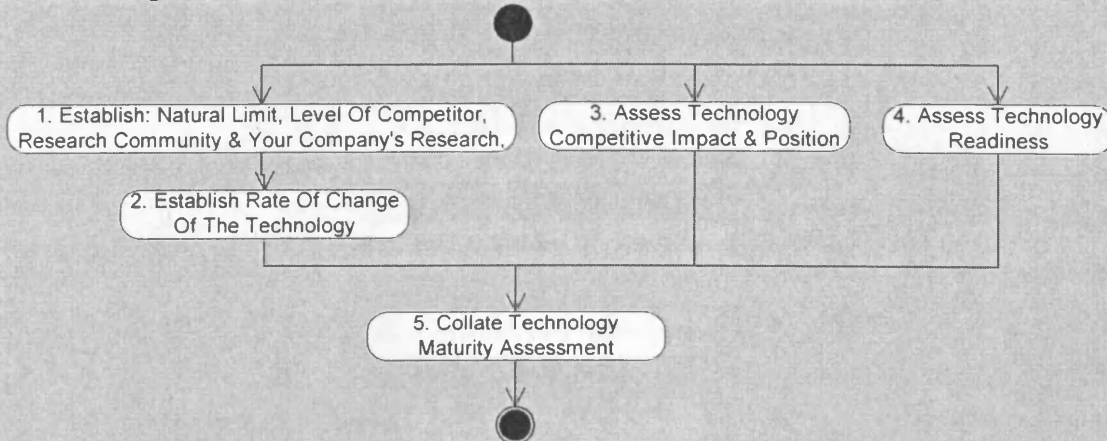
Purpose/Aim of Tool:

Technology maturity assessment aims to identify the maturity of a technology in terms of: at what stage is it in its lifecycle, its readiness for incorporation into products/services, and its competitive impact and position. This tool uses parts of the foot printing, trend model (S curve) and technology readiness levels tools.

When to use:

During the technology review phase of the lifecycle

Process: [uses both internal and mainly external resources]



Notes:

- 1 & 2. Establish a rate of change for the technology by (uses the technology trend model, e.g. the S curve):
Identifying the technology's natural limit
Establishing the level of the organisation's, competitors' and research community's research activity.
3. Assess the technology's competitive impact and position. This uses the technology foot printing tool.
4. Assess the technology's readiness to be incorporated into the product stream. The Technology Readiness Levels (TRLs) listed below are taken from NASA. These will need to be converted into levels that are meaning full for the organisation's business.

- TRL1 Basic principles observed and reported
- TRL2 Technology concept and/or application formulated
- TRL3 Analytical and experimental critical function and/or characteristic proof-of-concept
- TRL4 Component and/or breadboard validation in laboratory environment
- TRL5 Component and/or breadboard validation in relevant environment
- TRL6 System/subsystem model or prototype demonstration in a relevant environment (ground or space)
- TRL7 System prototype demonstration in a space environment
- TRL8 Actual system completed and "flight qualified" through test and demonstration (ground or space)
- TRL9 Actual system "flight proven" through successful mission operations

Additional Notes:

Technology demonstrators (from existing hardware) can be used to prove concepts, reduce risk, capture requirements and gain end user buy-in.

The rate of change of technology may be plotted, for example the technology S curve. Finding the points of inflection can be very difficult. In addition an organisation may find it difficult to control the process which determines the rate of change of technology.

Roles & Responsibilities

Process Owner:

Technology Manager

Participants:

Individuals from the business and from external organisations

(c) University College London

Technology Monitoring (Review of Sources of Technology Capability)

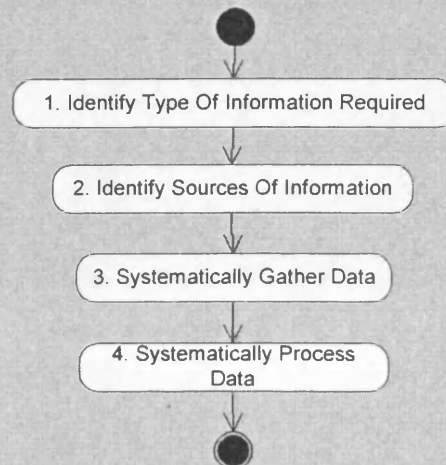
Purpose/Aim of Tool:

Technology Monitoring, or technology awareness, provides a systematic gathering and processing of information from a wide range of sources. Its aim is to direct focus to where a new development and existing knowledge can provide a possible innovation.

When to use:

During the technology review phase of the lifecycle

Process: [uses both internal and mainly external resources]



Notes:

1. This will help restrict the amount of data collected and processed and help identify potential sources.
2. This may at times be "easier said than done".
3. Having some form of automated collection/alert will help save time and avoid tying up to many resources. A suitable data base will be required to aid the retrieval and processing of the data.
4. Systematically process the data and report it in a form suitable for the other areas of the organisations that will be relying on the information.

Additional Notes:

New ideas can be acquired by buying smaller companies.

Conferences, Trade Journals, domain speciality clubs and Professional bodies can be a good source of information.

Internal forums can facilitate Knowledge exchange.

Roles & Responsibilities

Process Owner:

Technology Manager

Participants:

Individuals from the business and from external organisations

Technology Decision Making Tools

Purpose/Aim of Tool:

The technology decision making tool's aim is to provide senior management with the information they require in a format that is easy to understand to make technology development investment decisions.

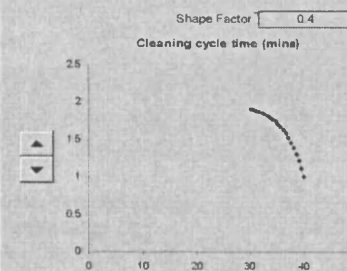
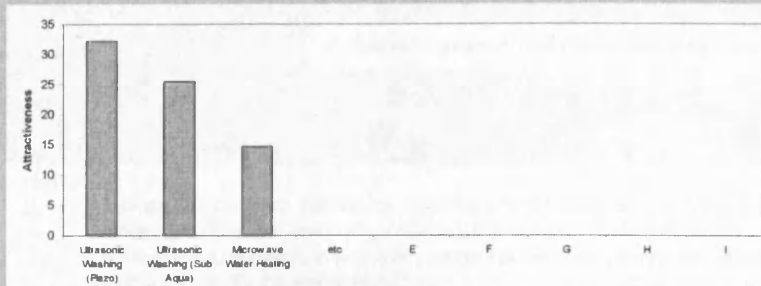
When to use:

During the preparation of the technology plan

Process: [uses internal resources]

Technology Solution Evaluation

	Solution Attributes							Implementation Factors			Overall Value
	Cleaning cycle time (mins)	Amount of detergent/chemicals used	Amount of Water Used	Unit Cost	Reduce Noise (dB)	Amount of Electricity Used (kWh)	Reduce maintenance costs by	Cost (£)	Time to Develop (yrs)	Impact on Products	
MIN	40	50%	30%	400	3	1.5	50%	50000	4	70%	32.25
IDEAL	30	30%	10%	250	6	1	50.0%	30000	0	100%	25.46
IDEAL Weight	2	1	1.5	4	3	2	3	1	3	1	14.96
Proposed Solution											
Ultrasonic Washing (Piezo)	35	10.0%	5.0%	380	4.5	1.50	50.0%	45000	5	0%	0.00
Ultrasonic Washing (Sub Aqua)	36	10.0%	5.0%	380	4.5	1.50	50.0%	55000	8	0%	0.00
Microwave Water Heating	30	10.0%	5.0%	350,000	3	1.00	30.0%	20000	2	0%	0.00
etc	40	1%	5.0%	500,000	3	1.00	1.0%	0	0	0%	0.00
E	40	1%	5.0%	500,000	3	1.00	1.0%	0	0	0%	0.00
F	40	1%	5.0%	500,000	1	1.0	1.0%	0	2	0%	0.00
G	40	1%	5%	500,000	1	1.00	1.0%	0	2	0%	0.00
H	40	1%	5.0%	500,000	1	1	1.0%	0	1	0%	0.00
I	40	1.0%	5.0%	500	1	1.00	1.0%	0	6	0%	0.00



The decision making process will usually involve a review of the technology options in terms of cost and benefits. Most organisations will have existing decision making forums/processes which can be adapted to include technology planning and investment decisions. The organisation may also have decision making tools that can be adapted. If existing tools are unavailable, it is fairly straight forward to develop a tool using spreadsheet software, see above.

Additional Notes:

Technology sourcing involves a compromise between keeping options open and backing a particular technology and involves a formal assessment of the attractiveness of technology.

Decision should include investment vs payback in future sales.

Collaborations and teaming can provide critical mass for technology development.

Step changes in the technology need to be assessed to indicate the impact on the supply chain.

Roles & Responsibilities

Process Owner:
Technology Auditor

Participants:
Individuals from the business and from external organisations

Technology Roadmap

Purpose/Aim of Tool:

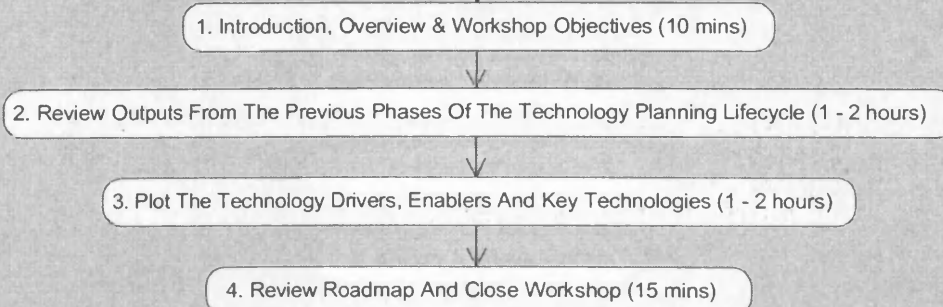
A technology roadmap's aim is to chart the key technology developments and milestones that support the products and services required to meet the future needs of the customer/market place.

When to use:

During the preparation of the technology plan

Process: [uses mainly internal resources]

A workshop is used to develop the road map. A typical workshop format (estimated duration shown in brackets):



Notes:

2. Review outputs from the previous phases of the technology planning lifecycle (The technology landscape (from the technology review), the output from any scenarios or technology games, customer future needs in terms of products & services), define the technology focus for each map and identify the key milestones.
3. Plot the technology drivers in terms of what and when is required on the roadmap. Plot the enablers to those technology drivers and the key technologies that support the enablers. Identify what the technology maturity level is required at each key milestone. Also note what resources are required in terms of investment etc. and identify any issues and areas of uncertainty.

Additional Notes:

A roadmap needs to be more than just a technology map. The map needs to chart where you want to be and how to get there and should include:

Drivers - business case (from different perspectives) of why you need to get to where you want to be

External Factors & Monitoring - outside influences beyond your control that require continuous monitoring

Enablers - political, buy-in, expectation management (higher mgt.)
- skills, training, support systems
- credibility, ownership, responsibilities

Technology - capability survey
- technologies
- standards
- implementation strategy
- expectation management (user)

Roles & Responsibilities

Process Owner:
Road Map Facilitator
Participants:
Individuals from the business

Technology Games

Purpose/Aim of Tool:

The aim of this tool is to integrate the results from the technology landscape (data collected by a number of tools and methods during the previous phase of the Technology Planning and Management Lifecycle) and uses a mathematical approach to select optimum strategies.

When to use:

During the preparation of the technology plan

Process: [uses mainly internal resources]



Notes:

1. Establish a structure for the game in terms of time and information.
5. Eliminate strictly dominant strategies, see note below.
6. Classify the solutions in the payoff matrix into in nash equilibrium (see note below) or not in equilibrium.

Additional Notes:

A strictly dominated strategy is a strategy that it will not be optimal for a player to follow regardless of the strategies of other players.

A Nash equilibrium is a solution where each player is happy to stick with his position given the positions of other players.

Roles & Responsibilities

Process Owner:
Technology Manager
Participants:
Individuals from the business

Technology Scenarios

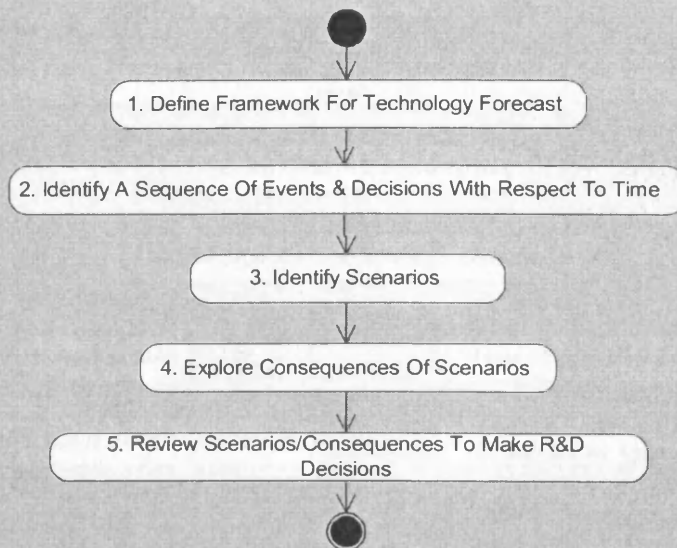
Purpose/Aim of Tool:

The aim of this tool is to integrate the results from the technology landscape (data collected by a number of tools and methods during the previous phase of the Technology Planning and Management Lifecycle) and/or investigating a situation with a high degree of uncertainty.

When to use:

During the preparation of the technology plan

Process: [uses mainly internal resources]



Notes:

- 3. Identify all scenarios resulting from the sequence of events and decisions made (each decision will result in a number of different scenarios).
- 5. Review the scenarios and their consequences to make R & D/technology investment decisions. (The output of The scenarios will be used in any roadmapping carried out and will ultimately feed into the decision making process Therefore any decisions made at this stage will probably to discard some of the unlikely scenarios).

Additional Notes:

The technology manager needs to make sure that the sequence of the events and decisions are consistent and that key decision trigger events are identified.

Scenarios can also be used when time series data, panels of experts or models are not available to the technology manager.

Roles & Responsibilities

Process Owner:
Technology Manager

Participants:
Individuals from the business

Exploit Existing Technology

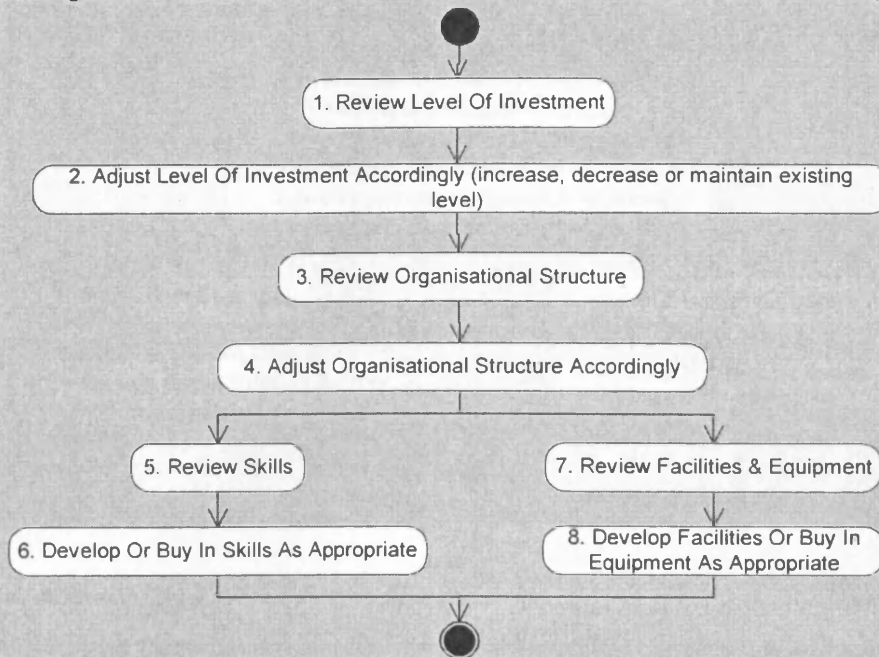
Purpose/Aim of Tool:

To exploit existing technology as part of the implementation of the technology plan.

When to use:

During implementation of the technology plan

Process: [uses both internal and external resources and processes]



Notes:

1. This review may have already taken place during the planning stage as part of the cost benefit analysis.

3 & 4. Create an environment & culture for technology development.

5 to 7. The latter part of this process requires senior management buy-in and commitment to provide the necessary resources (people, money, equipment etc.)

Additional Notes:

- Process requires management commitment as a large amount of resources may be required.

Roles & Responsibilities

Process Owner:

Senior & Functional Level Management.

Participants:

Individuals from the business and from external organisations

Introduce New Technology

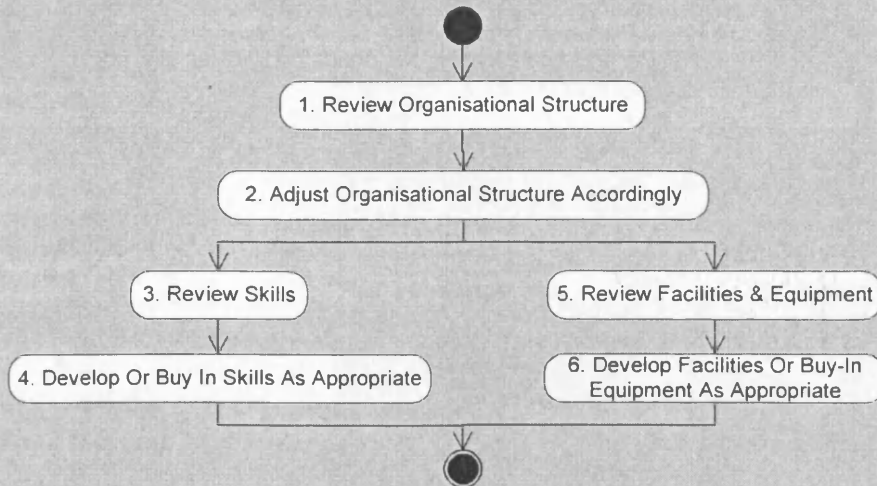
Purpose/Aim of Tool:

To introduce new technology as part of the implementation of the technology plan.

When to use:

During implementation of the technology plan

Process: [uses both internal and external resources and processes]



Notes:

3 & 4. Create an environment & culture for technology development.

5 to 7. The latter part of this process requires senior management buy-in and commitment to provide the necessary resources (people, money, equipment etc.)

Additional Notes:

- Process is similar to exploiting existing technology.
- Process requires management commitment as a large amount of resources may be required.
- If the technology being introduced is to replace an existing technology that is being disposed of, then this process needs to be used in conjunction with the disposal of technology process and co-ordination is required between the two to avoid any gaps arising.

Roles & Responsibilities

Process Owner:

Senior & Functional Level Management.

Participants:

Individuals from the business and from external organisations

Dispose Of Technology

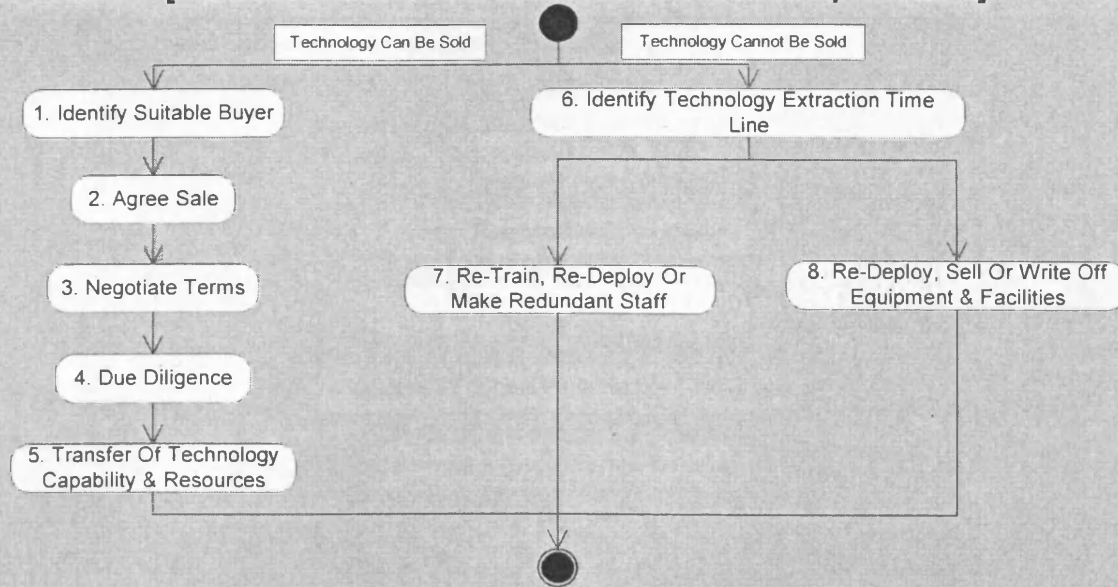
Purpose/Aim of Tool:

To dispose of an existing technology as part of the implementation of the technology plan.

When to use:

During implementation of the technology plan

Process: [uses both internal and external resources and processes]



Notes:

Determine if the technology can be sold.

If the technology can be sold:

- i. identify a suitable buyer
- ii. agree sale
- iii. negotiate terms
- iv. period of due diligence
- v. finally transfer the capability.

If the technology cannot be sold:

- i. define an extraction time line
- ii. look to redeploy, retrain or as a final resort make redundant employees associated with the technology
- iii. look to redeploy, sell or dispose and write off equipment.

Additional Notes:

- If the technology being disposed of is being replaced by a new technology, then this process needs to be used in conjunction with the introduce new technology process and co-ordination is required between the two to avoid any gaps arising.

Roles & Responsibilities

Process Owner:

Senior & Functional Level Management.

Participants:

Individuals from the business and from external organisations

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Technology Benchmarking

Purpose/Aim of Tool:

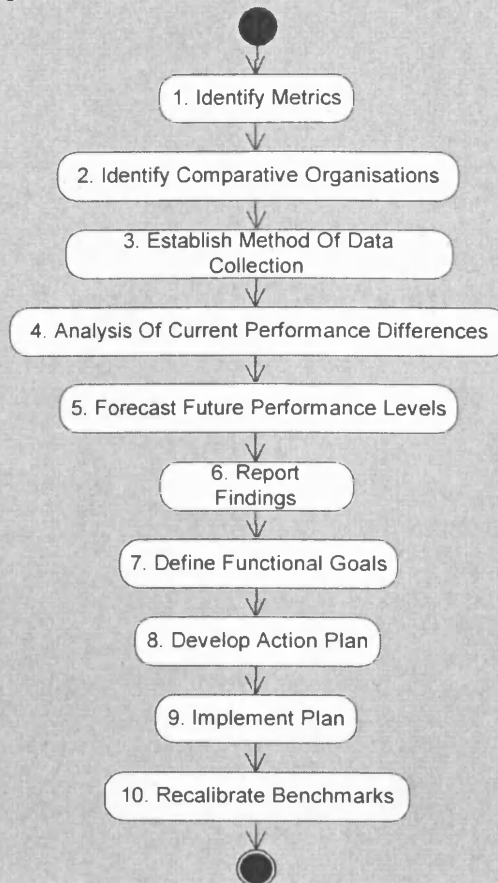
Technology Benchmarking is a process where agreed company performance factors are compared to "peer" organisations. The aim of benchmarking is to understand how an organisation compares to its competition and "best of breed" in other industries.

Benchmarking is an opportunity to get a 'heads up' view and to identify best practice and adopt it.

When to use:

During technology implementation monitoring

Process: [uses mainly internal resources]



Notes:

2. These can be competitors within the industry or world class organisations in different industries.

3. This can be difficult as some organisations will not want to give away 'trade secrets' that give away competitive advantage.

Additional Notes:

The last 4 parts of the process are aimed at providing feedback from the benchmarking process and to provide corrective action.

Recalibrate benchmarks to determine if improvement has been achieved.

This process requires employee buy-in to be successful.

Roles & Responsibilities

Process Owner:

Benchmarking facilitator

Participants:

Individuals from the business and from external organisations